QC
173
U54r
1948
v. 2

RADIOLOGICAL DEFENSE

Vol. II

The Armed Forces Special Weapons Project

RESTRICTED
Security Information

NATIONAL LIBRARY OF MEDICINE

NLM 00097461 8

UNITED STATES OF AMERICA

THE ARMY MEDICAL LIBRARY

FOUNDED 1836

U. S. ARMY
SURGEON GENERAL'S OFFICE
REFERENCE LIBRARY

WASHINGTON, D.C.

DOCUMENTS SECTION
ARMED FORCES MEDICAL LIBRARY

DUE TWO WEEKS FROM LAST DATE
AUG 1 3 1956
JUL 2 3 1957
JUN 25 1959
Staff
SEP 2 9 1994

QC
173
q U54r
v.2
1948

UNCLASSIFIED

RESTRICTED
Security Information

U.S. Joint Crossroads Committee

RADIOLOGICAL DEFENSE

Safety Manuals.

DEFENSE

Vol. II

CLASSIFICATION CHANGED
TO UNCLASSIFIED
AUTH E.O. 10501 1953
DATE SEP 21 1954
SECURITY OFFICER
Frank B Rogers

The Principles of

Military Defense against Atomic Weapons

Armed Forces Special Weapons Project

November 1951

RESTRICTED
Security Information

UNCLASSIFIED

U. S. Army troops participating in the first maneuvers based on military tactical employment of a nuclear weapon (Exercise "DESERT ROCK") near Las Vegas, Nevada, 1 November 1951.

qU584r
v. 2
1951
c. 1

ARMY MEDICAL LIBRARY
WASHINGTON, D. C., U. S. A.

While the atomic bomb is admittedly a weapon of great power, it is not to be regarded as an absolute weapon—that is to say, it is not a weapon against which there is no defense. Throughout history, the introduction of every new weapon has been followed by the development of defensive measures which have lessened its effectiveness. However, the development of suitable defensive measures against atomic weapons requires an understanding of the characteristics and effects of these weapons under various circumstances. Unfortunately, many misleading and exaggerated reports of the consequences of such weapons have received wide publicity, and these have made more difficult the task of those responsible for the planning of atomic defense.

In the event of a future war, a commander must consider the enemy's use of atomic weapons in his own strategic plans or tactical decisions. He also must know what precautionary measures will minimize the hazard to his own forces when taking advantage of the situation created by an atomic attack on the enemy. Further, in an emergency, each member of the Armed Services may have to act, possibly without warning, for his own protection. The purpose of the present volume, "Military Defense against Atomic Weapons," is to provide, in its true perspective, the essential background information which will make possible intelligent planning in advance and appropriate action in an emergency.

The first half of the book deals with the characteristics of atomic weapons, and with their effects on structures, equipment, and personnel, as far as they are of military significance. The final half considers the steps that may be taken to minimize these effects and to control their consequences. Since a relatively small number of atomic bombs has been detonated, so far, and there are many different conditions under which the weapon might be used, the information is necessarily incomplete. The conclusions drawn are thus the best that are possible in the circumstances, but are liable to change and improvement as more facts become available.

It should be emphasized that the radiological aspect of atomic defense is not necessarily the most important aspect. In the case of an air burst, for example, most casualties will be due to mechanical injuries and burns. However, radiation does present a novel feature of warfare resulting from the introduction of atomic weapons. It is for this reason that the subject of radiological defense is treated at some length.

It has been considered desirable in this volume to present the over-all picture of atomic defense as it applies to all three Services in a variety of circumstances. These may range from a situation in which there is direct contact with the enemy in the field or at sea, to that of an industrial type military installation adjacent to an urban area in the continental United States. While the individual problems in the different situations will inevitably be different, certain general principles will hold in every case. It is these fundamental principles which are covered herein.

Radiological defense, like other aspects of defense, will involve a number of specialized operations, such as use of instruments, survey of areas and equipment contaminated with radioactive material, and the decontamination of such areas and equipment. It is not the intent of this book to discuss these operations in detail, although their main principles and the parts they play in the general defense program are outlined. The operations will be performed by personnel trained especially for the various purposes, and for whom the individual Services are providing de-

tailed training and specialized technical manuals suited to their individual requirements.

This volume is the second of a series of Radiological Defense Manuals issued by the Armed Forces Special Weapons Project for indoctrination and training use in the Armed Services. Due to the additional time required to assemble the information required for this book, however, Volumes III and IV were completed and published prior to this present work. These other volumes deal with the medical aspects of atomic warfare and with radiac instruments, respectively. The original member of the series (Volume I) deals principally with nuclear physics. As has been indicated in the foregoing paragraphs, Volume II is intended to be the planning and operational member of this series.

The original drafts of the material for this volume were prepared at the Naval Radiological Defense Laboratory, San Francisco, partly from contributions of its staff and partly from material supplied by other representatives of the Armed Services who collaborated in this work. It is regretted that it is not feasible to list the names of the many individuals, both uniformed and civilian, who have assisted in the assembly and review of the contents of this book. Their efforts are sincerely appreciated. It is also desired to acknowledge the valuable assistance rendered by the Atomic Energy Commission in making available Dr. Samuel Glasstone, who acted as Executive Editor in the final rewriting and integration of the manuscript.

HERBERT B. LOPER
Brigadier General, USA
Chief, Armed Forces Special Weapons Project

TABLE OF CONTENTS

INDEX TO ILLUSTRATIONS

Chapter 1

HISTORICAL EXPERIENCE

THE ATOMIC BOMB IN WARFARE

The Hiroshima Bomb

1.01. The first use of the atomic bomb in warfare occurred on 6 August 1945, at Hiroshima, in Japan. This port city, which at the time had an estimated population of over 300,000 persons, military and civilian, lies on a flat, fan-shaped delta of the Ota River. Soon after 0800 on the aforementioned day, three United States aircraft appeared over the city, but little attention was paid to them. Half an hour before, the "all clear" had been sounded from an earlier warning and, consequently, all but a few persons had left the air-raid shelters and were on their way to work. It is estimated that some three-quarters of the population were then in the congested 4-square-mile center of the city, many of them still in the streets.

1.02. The bomb was dropped over the center of Hiroshima and exploded at a height of about 2,000 feet above the ground. This altitude was chosen deliberately, as will be seen later, in order to produce the maximum amount of damage to structures in the city. The explosion was accompanied by a brilliant flash of light and an intense wave of heat, that was felt nearly 4 miles away. Immediately thereafter came a violent blast of air the force of which destroyed, or rendered useless, buildings up to a distance of nearly 2 miles from the center of the explosion (figs. 1.02 a and b). As far away as 8 miles, glass was broken and plaster damaged. At the same time all public utilities—water, electricity, gas, transportation, and telephone services—were disrupted.

1.03 Due to the breaking of gas lines, the overturning of stoves and furnaces, and for other reasons, fires soon broke out in various parts of the city. Buildings damaged by the blast were particularly vulnerable to the spread of fire, and within 20 minutes of the detonation of the atomic bomb more than 4 square miles of Hiroshima were a mass of flames. However, little or nothing could have been done to restrict the conflagration. It is true that the fire-fighting services and equipment in Hiroshima were poor by American standards, but it is very doubtful if much could have been achieved, in the circumstances, by more efficient fire departments. Nearly 70 percent of the city's fire-fighting equipment was destroyed and about 80 percent of the firemen on duty were immediate casualties. Even if the men and machines had survived the blast, many places were inaccessible because of the streets being blocked with debris. Further, the damage to water pipes made the water pressure so low that it would have been of little use for controlling fires.

1.04. The atomic explosion over Hiroshima resulted in the death of about 70,000 persons and the injury of an almost equal number. Thus, nearly half of the city's population became immediate casualties. Many people became sick in subsequent weeks due to overexposure to the nuclear radiation that is a characteristic of the atomic bomb. The high casualty rate in Hiroshima was undoubtedly due to the fact, mentioned above, that at the time of the explosion a considerable proportion of the population was concentrated near the center of the city, with an unusually large number in the streets.

1.05. The three planes, which appeared over the city so soon after an "all clear" had been given, were not taken seriously. It was thought that they were observation planes, and even if they had been bombers, their bomb load was evidently not considered sufficient to merit a further disruption of the city's daily routine. From the standpoint of defense against the atomic bomb, the important lesson is that no enemy plane, whether it comes singly or in a group, can be disregarded. Had the inhabitants of Hiroshima remained in their shelters, the number of casualties would have been greatly decreased. The material destruction would presumably have been the same, but care of the injured and

Figure 1.02a. The Hiroshima Prefecture (approximately 1,000 yards from ground zero) before the atomic explosion.

rehabilitation and repair of the city after the explosion would have been greatly facilitated.

The Nagasaki Bomb

1.06. Three days after the attack on Hiroshima, at 1102 on 9 August 1945, an atomic bomb was exploded over the industrial seaport of Nagasaki, with a population of 230,000. The city lies on a small plain which extends up two relatively narrow valleys, between hills rising some 1,000 feet above sea level. The heavily industrialized part was located in the larger of the two valleys, and it was approximately 2,000 feet above this area that the bomb was exploded (fig. 1.06). As a result, the huge Mitsubishi Ordnance Plants, which were in the Arakami valley, were destroyed, but the harbor and commercial areas, and much of the residential area, escaped serious damage. One of the factors responsible was the hilly nature of the terrain. Many houses, built in ravines, were sheltered by the hills, and thus protected from the blast.

1.07. The fires which followed the blast spread more slowly and covered a smaller area (about 1.8 square miles) than at Hiroshima. There were two reasons for this. First, the factory area at Nagasaki, over which the bomb was dropped, contained less combustible material than the business and residential parts of Hiroshima. And second, the wind, which developed some time after the conflagration had become well established, tended to carry the fire up the valley in a direction where there was nothing to burn. Had the wind been in the opposite direction, toward the shore instead of away from it, the consequences might have been quite different.

1.08. Because of the tremendous psychological shock and the disruption of communications following the bombing of Hiroshima, reliable news was not available in other parts of Japan. Consequently, Nagasaki was little better prepared for the atomic attack, with the result that about 36,000 people were killed and 40,000 injured. The city had been on a warning alert for more than 2 hours before the bomb fell, but no raid alarm had been given and only a few hundred persons were in shelters. However, because of the time of day, and the different circumstances, the proportion of the population in the streets in Nagasaki was not so large as at Hiroshima. This may account, in part, for the smaller number of casualties.

Figure 1.02b. The Hiroshima Prefecture after the atomic explosion.

1.09. Since a large number of the inhabitants as well as considerable residential areas of the city survived the explosion, rescue efforts at Nagasaki were soon organized. The water supply was partially restored by the second day after the dropping of the bomb, and some electric power was available at the end of the same day. On the following day a few streetcars and railway trains were running again.

Studies of Damage and Casualties

1.10. The damage and casualties due to the atomic bombs at Hiroshima and Nagasaki are summarized in table 1.10. For purposes of comparison the corresponding figures are given for the destructive air raid on Tokyo on 10 March 1945, made largely with incendiary bombs, and the average of 93 air attacks on Japanese cities with similar weapons. The outstanding feature of the atomic bomb is seen to be the high casualty rate per square mile destroyed. Thus, atomic bombs have a greater "saturation" character than bombs of the more conventional type.

1.11. Soon after the cessation of World War II, teams of observers from the United States and from Great Britain went to Japan to make detailed studies of the effects of the atomic bombings on both structures and personnel. The main purpose of the studies was to obtain information useful in the development of defense measures. Comprehensive reports have been issued both by the United States Strategic Bombing Survey and the British Mission to Japan.

Table 1.10. Comparison of Casualties from Atomic and Conventional Bombs[1]

	Hiroshima Atomic Bomb	Nagasaki Atomic Bomb	Tokyo 1,667 tons Incendiary and TNT	Average of 93 Attacks 1,129 tons Incendiary and TNT per attack
Population per square mile	35,000	65,000	130,000	—
Square miles destroyed	4.7	1.8	15.8	1.8
Killed and missing	70,000	36,000	83,000	1,850
Injured	70,000	40,000	102,000	1,830
Mortality per square mile destroyed	15,000	20,000	5,200	1,000
Casualties per square mile destroyed	30,000	42,000	11,800	2,000

[1] "The Effects of Atomic Weapons," U.S. Government Printing Office, Washington, D.C.

Figure 1.06. Aerial photographs taken over Nagasaki before and after the atomic bomb explosion; circles of 1,000 and 2,000 feet radius are shown.

In addition, the Atomic Bomb Casualty Commission of the United States National Research Council, sponsored by the Atomic Energy Commission, is still (1951) in Japan investigating the possible delayed effects of the bomb on humans.

TEST ATOMIC EXPLOSIONS

The Alamogordo Test

1.12. The first atomic bomb actually to be exploded was that in the historic test held in the early hours of the morning of 16 July 1945, in a remote section of the Alamogordo Air Base in New Mexico. As seen above, the bomb proved to be a weapon of tremendous destructive power.

1.13. In the test at Alamogordo, the bomb was mounted on a steel tower, about 100 ft. above the ground. The great heat produced turned the steel into vapor, and the powerful force of the explosion caused a wide, shallow crater to form. The dirt and other debris disturbed by the blast was sucked up by a tremendous updraft, thus forming, with the residual bomb materials, a dense column of smoke. This rose rapidly to a height of nearly 5 miles before spreading out into the mushroom-shaped cloud characteristic of many atomic explosions.

1.14. Even before the explosion, most of the effects of the atomic bomb had been anticipated. Due precautions were accordingly taken to avoid injury to the personnel responsible for making observations both during and after the explosion. As a result, the bomb caused no casualties.

Operation CROSSROADS

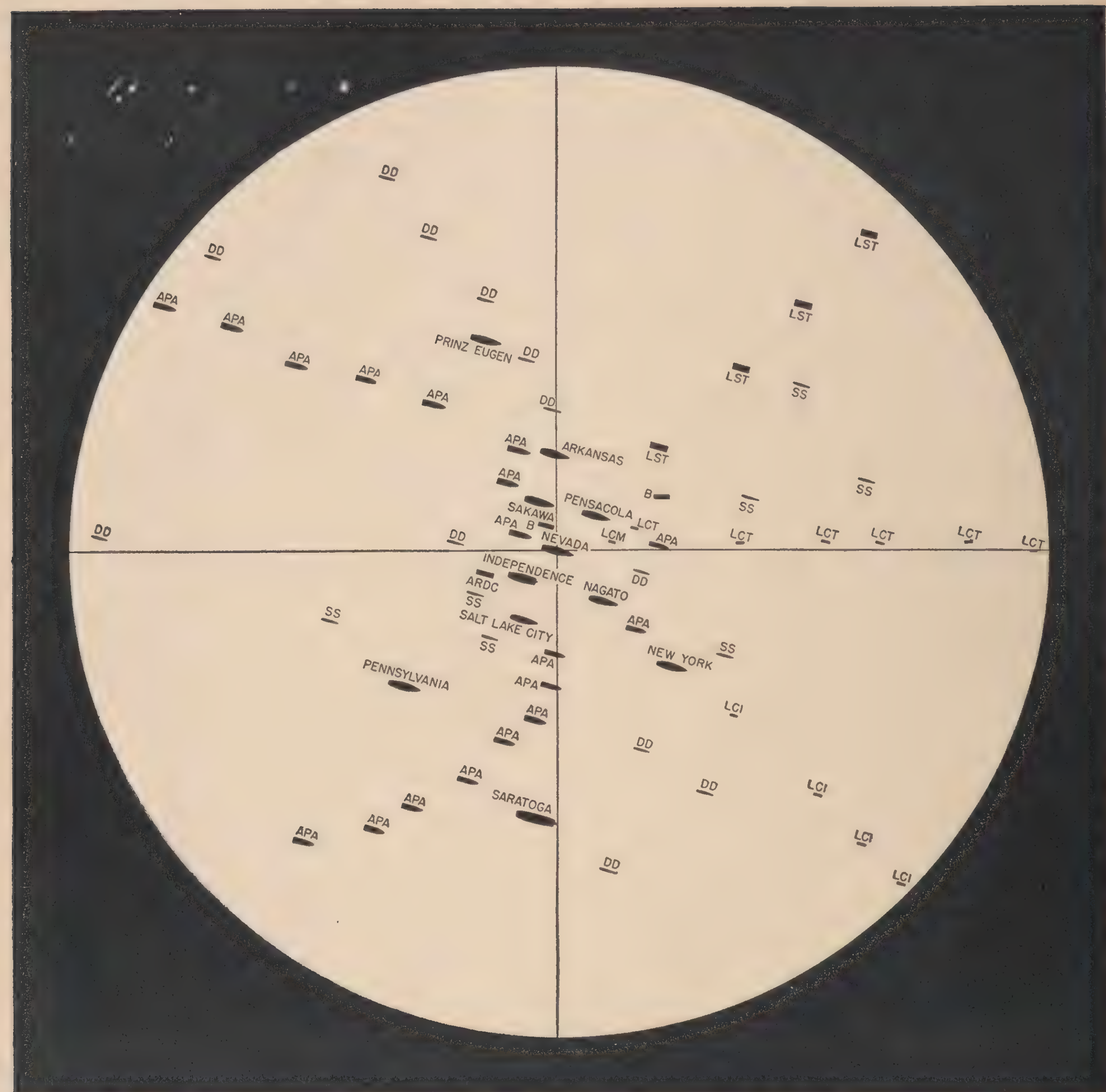
1.15. The three atomic explosions described above took place over land areas. In order to be in a position to protect the fleet in the event of an atomic war, the Navy, in particular, wished to know something of the effects of an atomic explosion at sea. Consequently, plans were set in motion for what was known as Operation CROSSROADS, a technical operation on a large scale, designed to supply data for naval and military defense against the atomic bomb. It was to be a joint effort of all the armed forces, and when actually carried out at Bikini in July 1946, it involved a total of 42,000 men, 242 ships, and 156 aircraft. Two bombs were exploded —one in the air (Test Able) and one under water (Test Baker). Among the 70 ships of various types forming the target array, there were 5 battleships, 2 aircraft carriers, 4 cruisers, 12 destroyers, 8 submarines, and many landing craft and merchant-type vessels.

Test Able

1.16. In Test Able, the central target vessel was the battleship NEVADA, and around it, within a radius of about 1,000 yards, were about 20 other ships. Outside this primary target area were spaced the remaining target ships along radial lines, somewhat like the spokes of a wheel (fig. 1.16). The ships were located much closer to each other than is usual under operating conditions because it was desired to obtain information as accurate as possible concerning the dependence on distance from the explosion of the whole range of damage, from complete loss, at one extreme, to complete immunity, at the other extreme.

1.17. On the decks of the target ships were exposed a wide variety of military equipment for test purposes: these included airplanes, ammunition, battle equipment, clothing, and packaged food. In addition, about 400 goats and pigs, and 5,000 rats were distributed throughout the target fleet so that the effects of the bomb on animals could be studied. To record the physical characteristics of the explosion, nearly 5,000 pressure gauges, 25,000 radiation-measuring instruments, 750 cameras and 4 television transmitters had been placed at strategic points on and around the target array.

1.18. The Test Able bomb, dropped from a B–29 flying at about 30,000 ft., burst a few hundred feet above the level of Bikini lagoon soon after 0900 on 1 July 1946. Immediately after the explosion, pilotless aircraft were flown over the target area. These planes, controlled by radio, were guided through the mushroom cloud to collect air samples for analysis. Then, planes with observers circled the lagoon, recording the damage visually and by means of cameras. A merchant-type vessel, the GILLIAM, the only target ship within 300 yards from surface zero, was seen to have sunk in less than a minute of the explosion. A destroyer, the ANDERSON, at less than 750 yards, was ablaze and sank in 8 minutes. Another merchant-type vessel, located about 1,000 yards from surface zero, sank some 40 minutes after the burst.



DD	DESTROYER	LST	LANDING SHIP TANK	LCM	LANDING CRAFT MECHANIZED
SS	SUBMARINE	LCI	LANDING CRAFT INFANTRY	ARDC	FLOATING DRYDOCK
APA	ATTACK TRANSPORT	LCT	LANDING CRAFT TANK	B	BARGE

Figure 1.16. Drawing of the Bikini Test Able target array as the bombardier might have seen it. In order to give accurate instrumentation of graded damage the concentration of ships was much higher than would normally be found in a tactical situation.

1.19. A second destroyer, the LAMSON, had capsized, and the Japanese cruiser SAKAWA was low in the water (fig. 1.19a). Both vessels sank slowly, the destroyer in 8 hours, and the cruiser on the morning of the day following the explosion. The light aircraft carrier INDEPENDENCE, less than 1,000 yards from surface zero, suffered severely (fig. 1.19b). The flight deck was bulged up and broken and the four stacks were demolished (fig. 6.97). Fire broke out on the hangar deck, adding to the general destruction.

1.20. Nearly all vessels within 1,000 yards of surface zero at the Bikini Test Able were either sunk or so badly damaged as to seriously impair their military efficiency. Moderate damage extended out to about 1,500 yards, and minor damage was experienced within a radius of 2,000 yards. Although the conditions of the explosion were not quite the same as those in the air bursts over Japan, it would seem that the area over which warships would suffer damage due to an atomic bomb is considerably less than for structures on land. This is to be expected, since warships are built to withstand a reasonable amount of blast. Military vehicles, such as tanks, which were exposed on the decks of some of the target ships, also proved to be resistant to damage. However, aircraft, similarly exposed, were found, by comparison, to be very vulnerable.

1.21. The number of fires aboard the ships was small. This was partly due to the relative absence of combustible matter on the decks. Such fires as did occur were mainly in packaged goods exposed for the test.

1.22. Patrols entered the lagoon about 2 hours after the detonation to determine whether it had been appreciably contaminated by the residue from the air-burst atomic bomb. Only a few areas were found to present any hazard, and in midafternoon the entire region was declared safe. The observing fleet then entered the lagoon. By sundown, 18 target vessels had been boarded and the recovery of scientific instruments and test animals was in progress. During the following week, inspection teams made a detailed examination of the damage suffered by the target ships and their contents.

Test Baker

1.23. The four preceding atomic explosions had all taken place in the air, and so Test Baker at Bikini presented a new feature, namely, an underwater burst. The bomb, in a watertight caisson, was suspended by a steel cable below a small landing vessel, the LSM–60. Around this was a new target array, again consisting of 70 ships of various types; 40 of these were within a mile of the LSM–60, while the others lay farther out. Each target vessel was fitted with gauges to determine strains in the hull, and with devices for measuring radiations that might arise from the exploding bomb. Instruments for determining underwater shock pressures and wave heights were placed in suitable positions.

1.24. At 0835 on 25 July 1946, the atomic bomb under the surface of Bikini lagoon was exploded by means of a radio signal. Instantaneously, a luminosity appeared in the water, rapidly followed by the formation of a dome-shaped bulge in the surface above the point of burst. A fraction of a second later a great hollow column or pillar of water began to rise at a great speed. This column, attaining a diameter of more than 600 yards, rose to a height of over a mile. The hollow stem, with walls believed to be some 100 yards thick, was capped by a huge cloud, giving the over-all appearance of a gigantic cauliflower (fig. 1.24). The total weight of water carried upward in the column was estimated to be well over a million tons.

1.25. Within a few seconds of the explosion, water from the column began to fall back into the lagoon and there developed at the surface, around the base of the hollow pillar, a great wave or cloud of mist, similar to clouds of spray formed at the bottom of Niagara Falls or other large waterfalls. This dense mist, which can be seen above the surface of the lagoon in figure 1.25, represents the initial stage of what has become known as the *base surge.*

1.26. In a very short time, the base surge cloud was roughly 1,000 feet high and moving rapidly outward, maintaining an ever-expanding, doughnut-shaped form. In about 3 minutes it reached its greatest expansion with an over-all diameter of some 3 miles. Then it drifted downwind, appearing gradually to lift from the surface of the water and merging with the cauliflower-shaped cloud (fig. 1.26). Some 15 minutes later the base surge cloud was entirely clear of the target array and was being lost among the natural clouds of the sky.

Figure 1.19a. The Japanese cruiser SAKAWA after Test Able at Bikini.

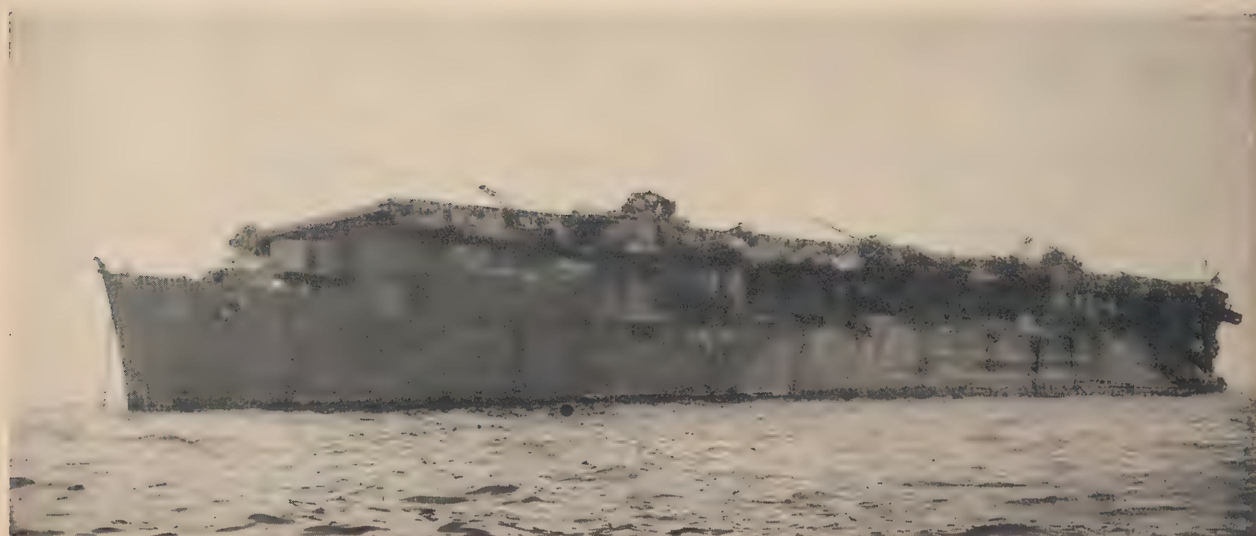


Figure 1.19b. The light aircraft carrier INDEPENDENCE after Test Able at Bikini.

Figure 1.24. The water column and "cauliflower" cloud formed by the underwater atomic explosion (Test Baker) at Bikini.

1.27. An intermittent, moderate rainfall, moving with the wind and lasting for nearly an hour after the explosion, developed from the cloud system. In its early stages, the rain was augmented by large amounts of water falling from the cauliflower cloud, and carrying with them considerable quantities of radioactive material.

1.28. When the base surge lifted, it was seen that the 34-year old battleship ARKANSAS, which had been near the LSM–60, had sunk, as also had a concrete oil barge and a landing craft in the vicinity, as well as the LSM–60 itself. Later, it was found that three submerged submarines had also been sunk. The aircraft carrier SARATOGA was low in the

Figure 1.25. Initial stage of the base surge at the base of the water column in Test Baker.

water and listing slightly to starboard (fig. 1.28). Many other ships showed obvious signs of severe underwater damage. In addition, measurements indicated that part of the energy produced by the explosion under water had been transmitted to the air. Because the water absorbed most of the heat from the bomb, there were no fires.

1.29. At first it was thought that the SARATOGA might be beached for examination, and salvage tugs entered the lagoon for the purpose. But it soon became apparent that the radioactive contamination of the carrier and the surrounding water was such that it might involve a hazard exceeding the rigorous tolerance limits imposed for the test operation. The

Figure 1.26. The base surge merging with the natural clouds of the sky.

tugs were therefore ordered to withdraw while the crippled SARATOGA slowly sank, disappearing completely under the surface of the lagoon by late afternoon.

1.30. In connection with contamination after the burst, Test Baker had an unexpected result from which important defensive lessons have been learned. The amount of water thrown into the air by the explosion had been predicted quite accurately, but some of the consequences of its return to the lagoon, particularly the base surge, had not been anticipated. The drops of water constituting the base surge cloud were highly contaminated with the residue from the

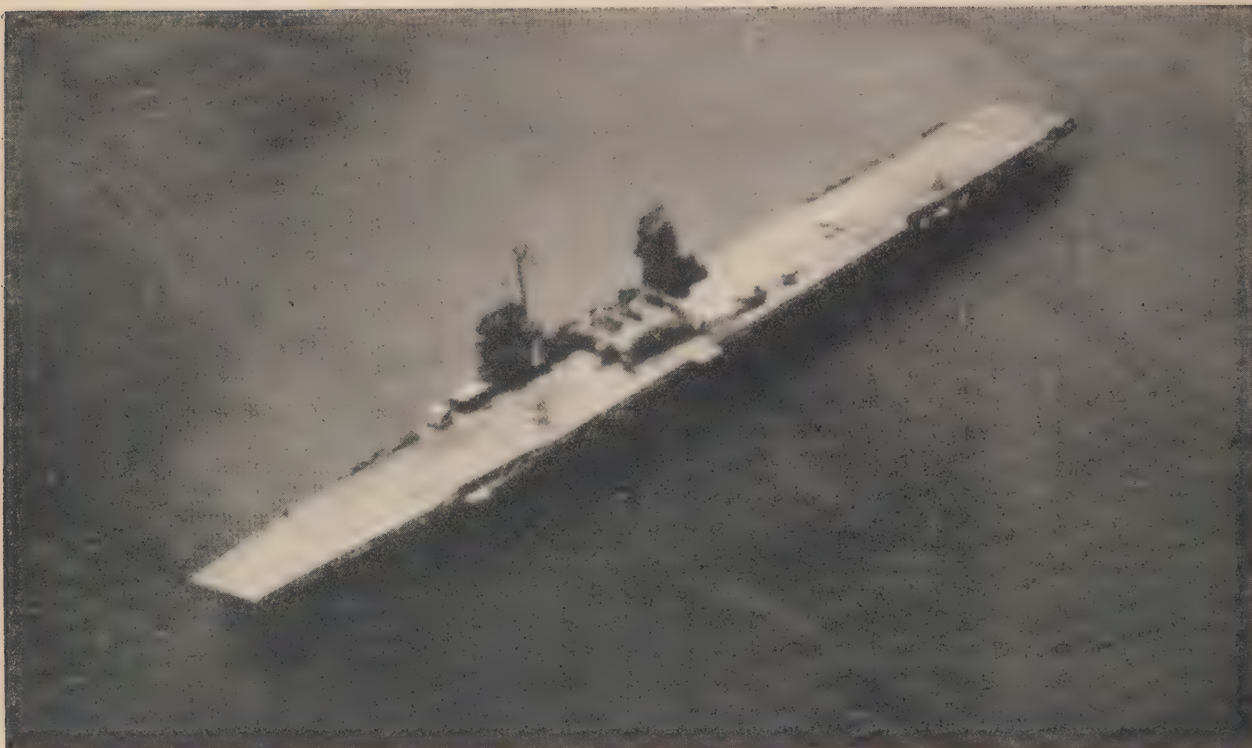


Figure 1.28. The aircraft carrier SARATOGA, several hours after Test Baker at Bikini. The damage to the stacks was not produced by air blast, but by mass movement of water.

atomic bomb, and these droplets, passing over and falling on ships, left them in a condition hazardous to human life.

1.31. Before the target vessels could be boarded, it was necessary to remove or decrease the radioactive contamination. This contamination cannot be neutralized nor destroyed, but it may be diminished in two ways. First, it may be washed, scrubbed, or blasted off, in one manner or another, from the surface to which it is attached, and thus diluted and transferred elsewhere, for example, into the sea. And second, advantage may be taken of the fact that all radioactive material undergoes a spontaneous decrease of activity with time, usually referred to as radioactive decay.

1.32. In general, both methods were used at Bikini following Test Baker. After the lapse of a few days, the contamination had decayed sufficiently to permit personnel to approach all ships without exceeding the tolerance limits which had been established for this peacetime operation. Then various emergency measures were adopted for preliminary decontamination to remove some of the radioactive material, so that the ships could be returned to the United States for examination.

1.33. A study of the damage provided valuable data to be used in the design of ships which might be subject to atomic attack. In addition, systematic efforts were made to develop simple and effective decontamination procedures. It is of interest to mention that two contaminated submarines were cleaned and returned to service free from risk to operating personnel. On the other hand, because of its battered condition no attempt was made to decontaminate the small aircraft carrier INDEPENDENCE. Yet, long before the vessel was disposed of, the natural decay had so decreased the radioactive contamination that the vessel could be occupied with complete safety.

Further Tests

1.34. In April and May, 1948, three atomic weapons of new design were tested at the United States Atomic Energy Commission Proving Ground on

Eniwetok Atoll, in the Marshall Islands. The major emphasis was on the scientific and technical aspects of weapons development. But, at the same time, important information, particularly in connection with the various radiations emitted by the bomb, was obtained that could be used for defensive purposes.

1.35. During 1951, further studies of the effects of atomic explosions have been made, both in the continental United States, at the Nevada Proving Ground, and at Eniwetok. The data obtained have served to improve our knowledge and understanding of atomic weapons. Much of the material contained in this manual is based on measurements and observations made at the various tests.

Atomic Explosions in Russia

1.36. The place of atomic defense in the nation's plans was given increased emphasis on 23 September 1949. On that day the President of the United States, in a brief announcement, told the world that this country was no longer the sole possessor of the atomic bomb.

"We have evidence that within recent weeks an atomic explosion occurred in the U. S. S. R.," the President said. "Ever since atomic energy was first released by man, the eventual development of this new force by other nations was to be expected * * *." Two additional Russian atomic explosions were announced by the President in October 1951.

CONCLUSION

1.37. The fact that a single bomb, which can be carried by a single plane, can cause essentially the same damage as TNT bombs requiring a thousand planes, has opened up a new era in offensive warfare. But, throughout history, the introduction of a new weapon has always been followed by the development of protective measures which have lessened its effectiveness. And in this respect the atomic bomb is no exception.

1.38. Since the atomic bomb is a relatively new weapon, it is evident that the history of atomic defense is short. Nevertheless, organizations in each branch of the armed forces have been making intensive studies of the problems of defense in atomic warfare. Every item of information, accumulated at Alamogordo, Hiroshima, Nagasaki, Bikini, Eniwetok and Nevada, as well as experience gained from other types of warfare, has contributed to the store of defensive knowledge. From this knowledge, new methods of coping with atomic attack are being devised.

1.39. The atomic weapon is known to be in the hands of at least one other power, and might consequently be used against this country's troops, ships, installations, and cities. Thus, an understanding of the characteristics of the atomic bomb and of the defensive measures which can be used to decrease its effectiveness is vital to all members of the Armed Services.

SUMMARY

The history of atomic defense began with the explosion of the bomb over Hiroshima, Japan, on 6 August 1945. This was the first time an atomic weapon had been used in warfare. Because of a lack of preparation and the fact that much of the population was in the streets at the time of the explosion, the proportion of casualties was high. Three days after the attack on Hiroshima, an atomic bomb was dropped on Nagasaki, Japan. Due to the nature of the terrain and the direction of the wind, and the fact that fewer people were in the open, the proportion of casualties at Nagasaki was smaller.

After the war, trained observers went to Japan to make detailed studies of the effects of the atomic bombings on structures and personnel. In this way, much information vital to the planning and organization of atomic defense has been obtained.

Operation CROSSROADS, carried out at Bikini in July 1946, was a large-scale technical operation, designed to supply data for naval and military defense against the atomic bomb. Two bombs were exploded: one in the air (Test Able) on 1 July 1946 and the other under water (Test Baker) on 25 July 1946. Subsequently, a number of other tests have been carried out and these have greatly improved our understanding of the effects of atomic explosions.

The information gathered at Hiroshima and Nagasaki, as well as that obtained from various test explosions, is being used as a basis for devising new methods of coping with the effects of the atomic bomb. Since the weapon is known to be in the hands of at least one other power, it is necessary that all members of the Armed Services should become familiar with its characteristics, and with the defensive measures which can be taken to decrease its effectiveness.

Chapter 2

THE ATOMIC EXPLOSION

THE RELEASE OF NUCLEAR ENERGY

Comparison of Atomic and HE Explosions

2.01. The atomic bomb was designed as a blast weapon. Its destructive effect, like that of an ordinary, high-explosive bomb, is due mainly to the blast or shock that follows the explosion. While in this respect the atomic bomb is similar to, although immensely more powerful than, the bombs with which military men have long been familiar, there are some fundamental differences in other respects (fig. 2.01). These differences have an important bearing on the problems of atomic defense. The present chapter will consequently be devoted to a consideration of the characteristics of the atomic bomb, with special reference to the ways in which it resembles and differs from ordinary HE bombs.

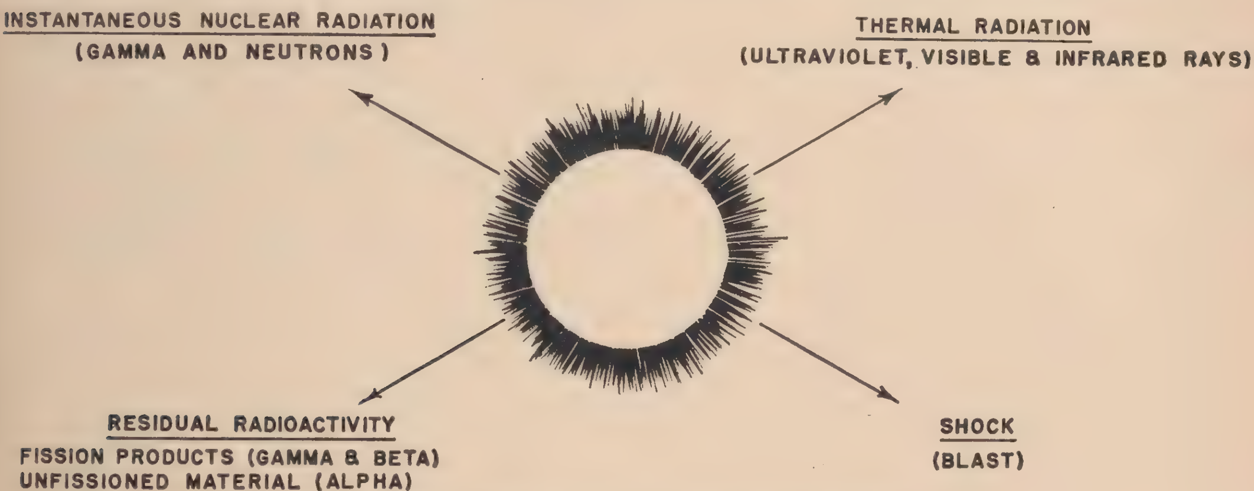


Figure 2.01. Schematic representation of an atomic explosion.

2.02. In general, the explosion of a bomb results from the release of a large amount of energy in a short interval of time within a limited space. The liberation of this energy is accompanied by a rise of temperature, so that the products of the explosion become extremely hot gases. These gases, at high temperature and pressure, move outward rapidly. In doing so they push away with considerable force the surrounding medium—air, water, or earth—thus causing the destructive effects of the explosion.

2.03. In an HE bomb, the energy is produced as a result of a rapid chemical reaction, namely, the decomposition of the explosive material. The atoms of the elements carbon, nitrogen, and oxygen, in TNT for example, undergo a rearrangement leading to the formation of a number of new substances, especially nitrogen, and oxides of nitrogen, and of carbon. This particular change in arrangement of these atoms is accompanied by the release of considerable amounts of energy.

2.04. An atomic or nuclear explosion resembles chemical explosions in the respect that it is due to the rapid release of a large amount of energy. But the difference lies in the fact that in the atomic explosion the energy results from rearrangement within the central portion, or nucleus, of the atom, rather than among the atoms themselves as in a chemical explosion. Since the energy changes accompanying nuclear rearrangements are very much larger than those associated with chemical reactions, the force of the explosion is correspondingly greater.

Nuclear Fission

2.05. The materials which have been used so far to produce atomic explosions are certain forms (isotopes) of the heavy elements uranium and plutonium. When a neutron, which is an uncharged atomic particle, enters the nucleus of the appropriate atom, it can cause the nucleus to break into two more-or-less equal fragments. Each of these frag-

ments is the nucleus of another, lighter, element. This process, whereby a nucleus of a heavy element splits into two nuclei of lighter elements, is called *fission* (fig. 2.05).

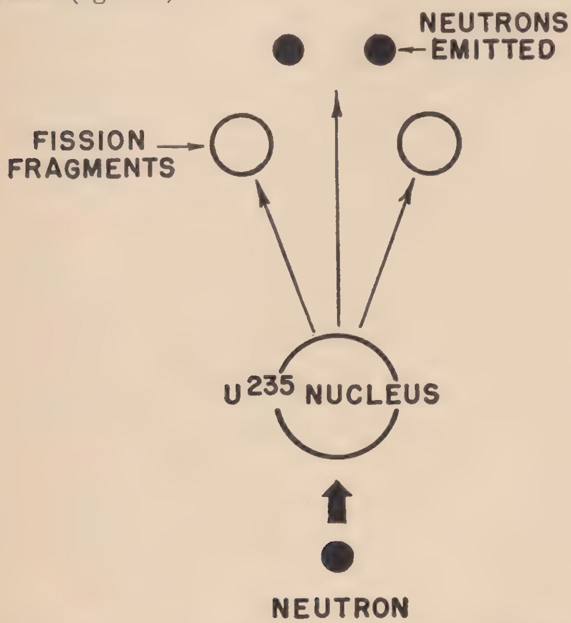


Figure 2.05. The fission of Uranium–235 by a neutron. The process is accompanied by the formation of fission products and the release of other neutrons.

2.06. The use of nuclear fission as a means of producing a tremendous explosion depends on two facts. First, the amount of energy released, when a given weight of uranium or plutonium undergoes fission, is several million times as great as that which would be liberated by the explosion of the same weight of TNT. The large energy release is due to the fact that the total mass of the fission fragments (and other atomic particles which may be formed simultaneously) is less than the mass of the nucleus undergoing fission plus that of the neutron initiating the process. It is the mass which is "lost" in the fission process which appears as an equivalent amount of energy.

2.07. The actual loss of mass in the fission of uranium or plutonium is only about one-tenth of a percent of the total. That is to say, if all the atomic nuclei in 1 pound of uranium or plutonium undergo fission, the decrease of mass would be roughly one six-hundredth part of an ounce. Nevertheless, the amount of energy released by the disappearance of this quantity of matter would be about the same as that produced by the combustion of 1,500 tons of coal or of 250,000 gallons of gasoline, or by the explosion of over 9,000 tons of TNT!

Nuclear Fusion—The Hydrogen Bomb

2.08. It may be mentioned that the phenomenon of conversion of mass into energy is going on in the sun and in many stars. Every second the sun loses about 4 to 5 million tons of matter, which appears as energy. The enormous amounts of energy released continually by the sun and by other heavenly bodies is, however, not due to nuclear fission, as in the atomic bomb, but rather to a process of nuclear *fusion*. It is believed that as a result of a complicated series of changes, nuclei of the lightest known element, hydrogen, are combined (or fused) together to form a nucleus of the heavier element helium. Broadly speaking, it is this alternative energy-releasing process of nuclear fusion which has led to the suggestion that this also might be used in the construction of atomic bombs. This proposed type is commonly referred to as the "hydrogen bomb."

Fission Chain Reaction

2.09. In addition to the large amount of energy released, the second important fact, which has made possible the production of an explosion as a result of fission, is that the process is accompanied by the release of two or more neutrons (see fig. 2.05). Thus, when a plutonium or uranium nucleus is broken up into two nuclei of lighter elements, by the capture of a neutron, two (or more) neutrons are simultaneously set free. The neutrons thus liberated in the fission process are able to cause the fission of other uranium or plutonium nuclei; in each case, more neutrons are released, which can produce further fission, and so on. Hence, a single neutron could start off a chain of fissions, the number of nuclei involved increasing at a tremendous rate (fig. 2.09).

2.10. Because of the rapidly growing chain, just described, several pounds of uranium or plutonium could undergo fission in a one-millionth part of a second. The energy accompanying the fission of this quantity of material would be enormous in amount, as seen above, and its release in such a short period of time could lead to a tremendous explosion, as it does, in fact, in the atomic bomb.

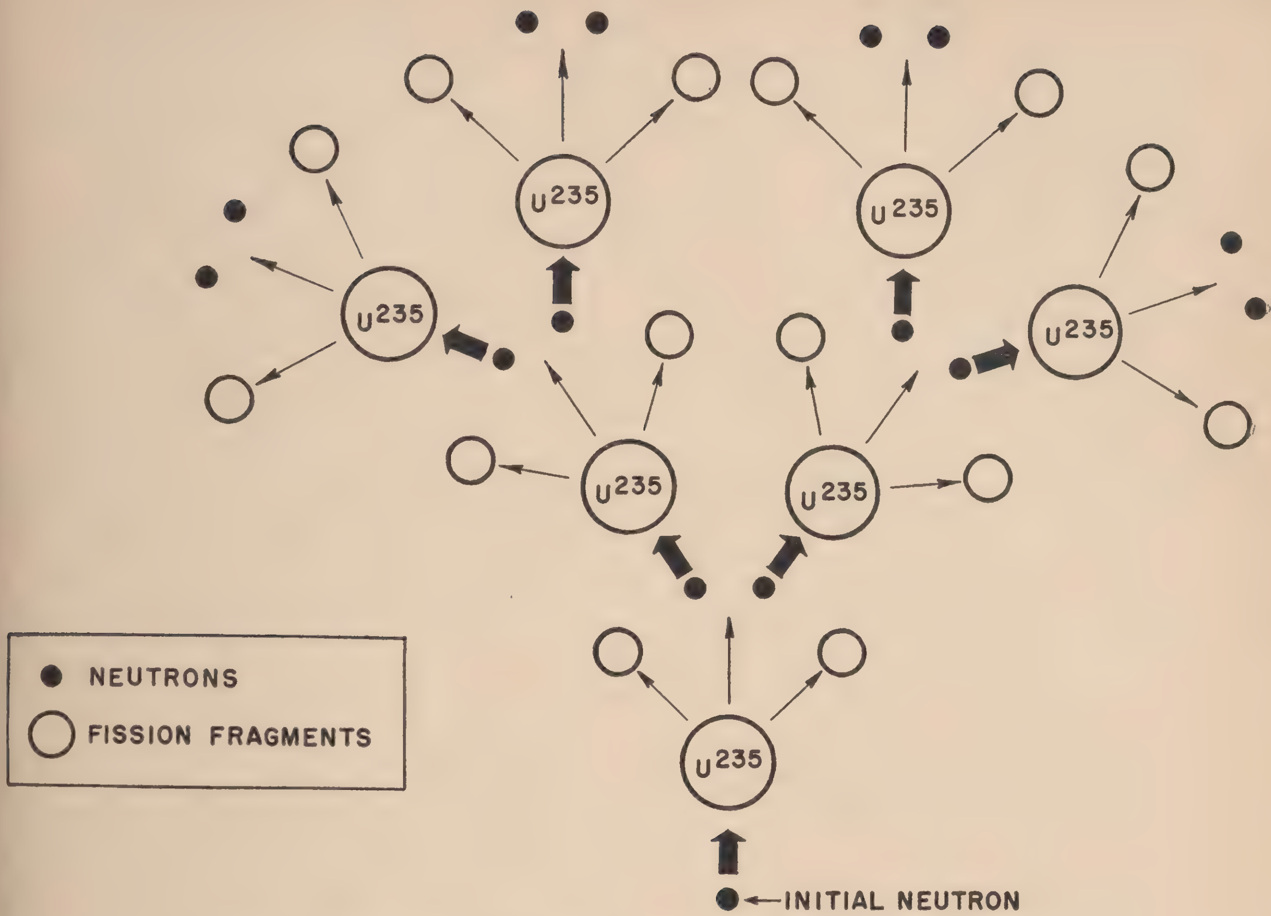


Figure 2.09. Representation of the first three stages of a fission chain initiated by a neutron.

Critical Size of Atomic Bomb

2.11. In the fission chain described above, not every neutron set free is successful in causing the fission of another nucleus. Some neutrons are captured by nuclei which do not undergo fission, while others escape and are lost, as far as fission is concerned. If an explosive chain reaction is to take place, the loss of neutrons must be prevented or, at least, made as small as possible.

2.12. The most practical way of minimizing the escape of neutrons is to increase the size of the fissionable material (uranium or plutonium). This may be illustrated by means of figure 2.12. Fissions are caused by neutrons in the interior of the mass, but those near the outside are lost. Hence, in the small mass, at the left, it is seen that the number of neutrons escaping is large in comparison with those causing fissions. In the larger mass, at the right, on the other hand, the proportion of neutrons lost is seen to be smaller. While the actual number escaping may increase somewhat, this is more than offset by the larger increase in fissions.

2.13. As the size of the uranium or plutonium is increased, a point is reached at which the chain reaction becomes self-sustaining, once it has been initiated. This is referred to as the *critical size* of the bomb, corresponding to which there is a critical mass. Therefore, in order to cause an explosion of fissionable material, the quantity must exceed the critical amount. This depends, among other things, on the nature of the material used in making the atomic bomb, and on the presence of other substances which capture neutrons but which do not undergo fission. By surrounding the uranium or plutonium with a suitable neutron "reflector," the

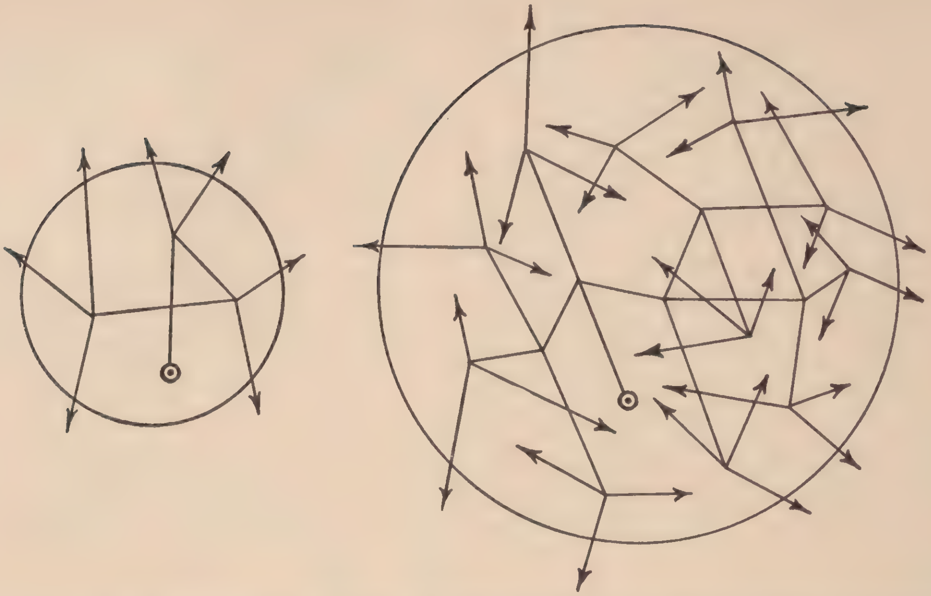


Figure 2.12. Illustration of the effect of increasing size of the fissionable material in reducing the proportion of neutrons lost by escape.

loss of neutrons by escape can be reduced, and hence the critical mass may be diminished to some extent.

2.14. The atomic bomb thus differs from ordinary HE bombs in an important respect. While there is, in a sense, no lower limit to the size of an HE bomb, which may contain any desired amount of explosive, from a few ounces or so up to several tons, an atomic bomb must contain at least the critical mass of fissionable (explosive) material. Consequently, the power of ordinary HE bombs can be small or large, whereas it may not be possible to make a "small" atomic bomb, that is, one with a low enough explosive energy to be comparable to even the largest HE bombs.

2.15. Because of the presence of stray neutrons in the air, a quantity of fissionable material larger than the critical size would be liable to explode. Therefore, it is necessary that before detonation the bomb should not contain any single mass of fissionable material which would exceed the critical size. But, in order to achieve the explosion the total fissionable material must be brought beyond the critical point. For example, before detonation the bomb might consist of two separate parts, each of which is less than the critical size. To cause an explosion, these parts would be brought together rapidly. Extreme rapidity is essential because, if the chain reaction were to start before the parts reached their closest position, the result would be a relatively weak explosion.

Energy of Atomic Bomb

2.16. It was reported that the energy released by the atomic bombs exploded over Hiroshima and Nagasaki was equivalent to that which would be obtained by the explosion of 20,000 tons, that is, 20 kilotons, of TNT. The energy release of the test bombs at Bikini was about the same. A bomb of this size is generally referred to as a "nominal" atomic bomb. The descriptions in this manual will apply, in particular, to the nominal atomic bomb, sometimes called a "20-kiloton TNT energy equivalent" bomb. Bombs of other energies can undoubtedly be made, and so instructions will be given for scaling the effects of the nominal atomic bomb so as to indicate what might be expected from other atomic bombs.

2.17. It will be obvious that the energy released by even a single nominal atomic bomb must be very considerable, if it is equivalent to that produced by the explosion of 20,000 tons of TNT located at one point. Some idea of the magnitude of this energy

may be obtained by stating it in another way.[1] It is about the same as the daily electrical output of Hoover Dam. It is more than the energy produced by running a 100-horsepower engine continuously for 30 years. In the atomic bomb all this energy is released in about a one-millionth part of a second. It is not surprising that the resulting explosion is of tremendous magnitude.

2.18. It was stated earlier, that the complete fission of 1 pound of uranium or plutonium will release the same amount of energy as the explosion of some 9,000 tons of TNT. Consequently, in the nominal atomic bomb, which has an energy release equivalent to that of 20,000 tons of TNT, about 2.2 pounds of material undergoes fission. The actual weight of uranium or plutonium in the nominal atomic bomb is greater than this amount. In other words, only a part of the fissionable material suffers fission at the instant of the atomic explosion, and the remainder is widely dispersed.

NUCLEAR RADIATIONS FROM THE ATOMIC BOMB

Instantaneous Gamma Rays and Neutrons

2.19. In the explosion of TNT, or other chemical explosive, nearly all the energy appears immediately as kinetic energy. This causes the gaseous products to attain high temperatures and pressures, which lead to the destructive effect of the explosion, as already explained. In the atomic bomb, about 85 percent of the total energy released is in the form of kinetic energy at the time of the burst. Most of this appears in the form of shock or blast (fig. 2.19). Another 5 percent is produced at the instant of the explosion in the form of what are called instantaneous *nuclear radiations*, since they come from the nuclei of various atoms. Half of this energy is carried by neutrons which escape from the bomb, and the other half by *gamma rays*. The latter are highly penetrating, invisible radiations, similar in nature to X-rays.

Radioactivity of Fission Products

2.20. The remaining 10 percent of the energy of the atomic explosion is released as nuclear radiations from the products of the fission of the bomb material (uranium or plutonium). It is because of these radiations that the residue from the atomic bomb is a source of radioactive contamination, as mentioned in the preceding chapter. In this respect, the atomic bomb differs fundamentally from HE bombs. The substances which remain after the explosion of TNT, for example, are mainly gases and are no more harmful than automobile exhaust in an open space.

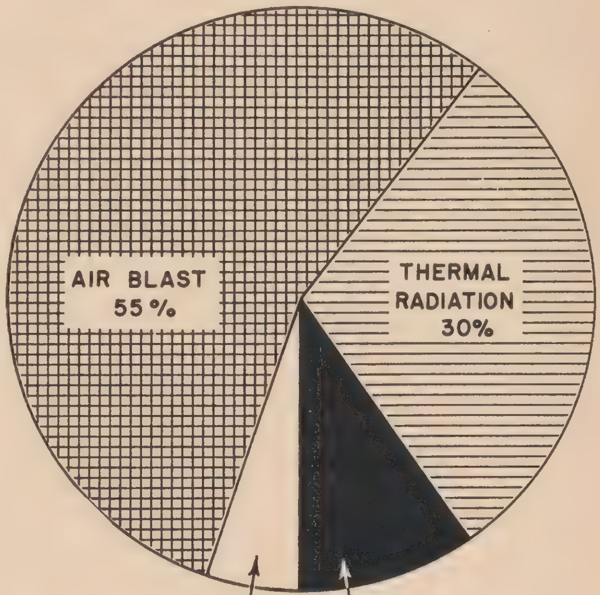


Figure 2.19 Distribution of energy in an atomic explosion in the air.

2.21. Uranium and plutonium nuclei can split up in 30 to 40 different ways, but in every case the resulting fission fragments are radioactive forms (radioisotopes) of well-known, lighter elements. The fission product nuclei consequently emit both gamma rays and another type of nuclear radiation called *beta particles*. The latter are electrons, i.e., atomic particles which carry a negative electrical charge, moving with high speed.

2.22. Gamma rays can travel great distances through the air and, like X-rays, can pass through considerable thicknesses of materials. It is because gamma rays can neither be seen nor felt by human beings, but can have harmful effects, even at a distance, that they are an important aspect of an atomic explosion. Beta particles are much less penetrating

[1]Expressed in more technical units, the energy released by a nominal atomic bomb is about 2×10^{13} calories $= 8.4 \times 10^{20}$ ergs $= 2.3 \times 10^{7}$ kilowatt-hours.

than gamma rays, but in certain circumstances they may also represent a hazard, as will be explained in chapter 7.

Radioactive Decay

2.23. The spontaneous emission of beta or other particles and of gamma rays from a radioactive material, such as the fission products, is a gradual process. It takes place over a period of time, at a rate depending on the nature of the material and on the amount present. The rate of radioactive change, i.e., the rate of emission of beta particles and gamma rays, is usually expressed by means of the *half life.* This is defined as the time required for the radioactivity of a given amount of a particular material to decrease (or decay) to half its original value. Each individual radioactive species has a definite half life which cannot be changed in any known way.

2.24. When a beta particle is expelled from the nucleus of a radioactive substance, the latter is changed into another element, sometimes called the decay product. In the case of the fission fragments, the decay products are usually also radioactive, expelling both gamma rays and beta particles. On the average there are about three stages of radioactivity for each fission fragment before a stable, nonradioactive, substance is formed. Since the direct products of fission start to decay as soon as they are formed, their decay products begin to accumulate and decay in turn. Ultimately, the activity of the fission products becomes negligible.

Decay of Fission Product Activity

2.25. As seen above, uranium and plutonium nuclei can undergo fission in many different ways, and each of the 60 or more primary fragments decays to form two or three successive radioactive species. The fission products thus form a very complex radioactive mixture. Consequently, although all the constituents have definite half lives, ranging from a small fraction of a second to many years, it is not possible to represent the decay of the mixture as a whole in terms of a half life.

2.26. From experimental measurements made over an extended period of time, it has been found that the total radiation intensity, due to a given quantity of fission products, at a time t hours after an atomic explosion, can be obtained fairly accurately from the decay formula:

$$R_t = R_1 t^{-1.2}$$

where R_1 = intensity or activity 1 hour after explosion
t = any time after the explosion
R_t = intensity or activity at time t

Thus, if the activity after 1 hour is known, or can be determined in some way (ch. 8), it is possible to use the formula to calculate the activity at any required time after the explosion. On the other hand, if the radiation intensity is known at any time t hours after the atomic explosion, the intensity due to that same quantity of fission products can be calculated at 1 hour after the burst.[2]

2.27. The manner in which the fission product activity decays after an atomic explosion is represented by the graph in figure 2.27, which is based on the formula given above. For convenience, the radiation intensity is taken as 100 at 1 hour after the explosion. It is seen that the activity falls off very rapidly soon

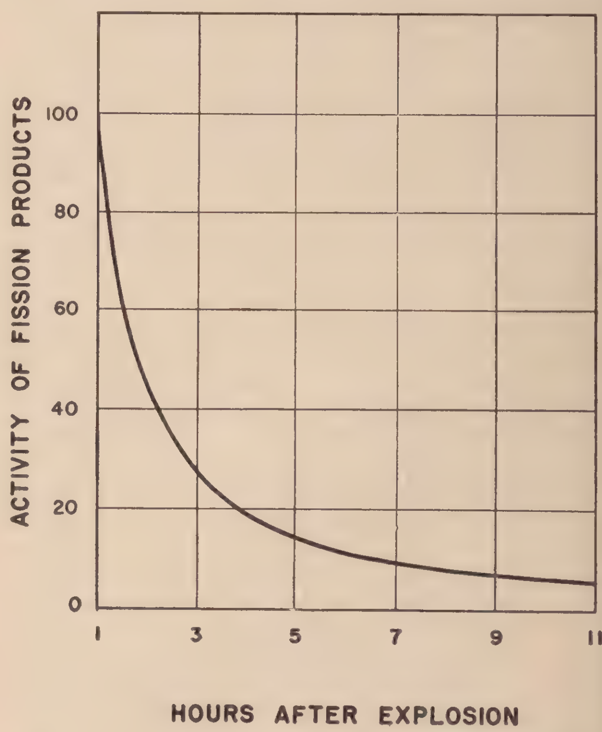


Figure 2.27. Rate of decay of fission products after an atomic explosion; the radiation intensity is taken as 100 at 1 hour.

[2] See appendix II for further details.

after the burst. Thus, at 4 hours it is one-fifth and at 7 hours it is one-tenth of that at 1 hour after the explosion. It is true that the activity does not diminish so much in the later stages, but the important point is that soon after the explosion, when the radiation intensity is highest, the activity falls off most rapidly.

2.28. It should be understood that the results given above apply to the complete mixture of fission products formed in an atomic explosion. The presence of appreciable quantities of substances in which radioactivity has been induced by neutrons, such as radioactive sodium for example (par. 3.64), would change the situation. This would also be the case if radioactive materials, due to causes other than fission, were present (ch. 5).

Alpha Particles

2.29. In addition to the radioactivity of the fission products which persists after an atomic explosion, there is another kind of activity that must be mentioned. This is the activity of the original bomb material which remains after the burst. Both uranium and plutonium are radioactive, primarily expelling *alpha particles*. These are positively charged particles, identical with the nuclei of helium atoms. Since they are expelled from atomic nuclei they are a form of nuclear radiation.

2.30. Alpha particles have such a low penetrating power that they cannot travel more than 1 to 3 inches in air before being stopped. It is doubtful, therefore, whether these particles can get through the unbroken skin, and they certainly cannot penetrate ordinary clothing. Consequently, uranium and plutonium do not constitute a hazard if they are anywhere outside the body. But, if plutonium, in particular, enters the body in sufficient quantity, the effects can be serious.

THERMAL (HEAT) RADIATION FROM ATOMIC BOMB

Comparison of Atomic and HE Bombs

2.31. The production of nuclear radiations, both during and after the explosion, constitutes the fundamental distinction between atomic and HE bombs. There is, however, another difference which, like the blast effect, is essentially one of degree. In the explosion of a TNT bomb the maximum temperature reached is about 5,000° C., but because of the much greater energy release in a small space a temperature of more than 1,000,000° C. is attained in an atomic explosion. This is not greatly different from the temperature in the interior of the sun.

2.32. The exploding bomb, consequently, behaves like a miniature sun, radiating a considerable amount of heat. In fact, about one-third of the energy of the bomb, roughly 8 million kilowatt-hours, is emitted as heat radiation, or *thermal radiation*, as it is generally called. In the case of an air burst of a nominal bomb the intensity of the radiation is sufficient to cause burns of exposed skin as far as 2 miles away, on a moderately clear day. The warmth may be felt at a distance of 10 miles.

2.33. An ordinary HE bomb also produces a certain amount of thermal radiation when it explodes, but this is very much less than in an atomic explosion. The effects are thus not noticeable at any great distance away. Even if 20,000 tons of TNT were exploded the radiation would not approach that of an atomic bomb because of the much greater volume occupied by the explosive material. If, in some way, this mass of TNT could be compressed so as to occupy the same space as the fissionable substances in an atomic bomb, the thermal radiation effect would be similar to that of an atomic bomb.

SUMMARY

The explosion of an atomic bomb resembles that of an ordinary HE bomb in the respect that it is due to the rapid release of a large amount of energy in a small space. The energy produced in the HE bomb is due to a chemical reaction, and in the atomic bomb it results from a nuclear process, namely—the fission (splitting) of nuclei of particular forms (isotopes) of the elements uranium or plutonium. However, weight for weight, the energy released in fission is millions of times greater than that produced by a chemical explosive. It is this great concentration of energy, and its rapid liberation, in about a one-millionth part of a second, that accounts for the tremendous power of the atomic bomb.

At least half of the total energy of the bomb contributes to the blast or shock effect. The atomic bomb is thus essentially a blast weapon, like an HE bomb.

The large energy release in a small space in an atomic bomb results in the attainment of a very high temperature, approaching that in the interior of the sun. Consequently, an intense thermal (heat) radiation, carrying about one-third of the total fission energy, emanates from the bomb. It can produce slight skin burns as far away as 2 miles, on a moderately clear day, and the warmth may be felt more than 10 miles away.

A small amount of the bomb energy is carried off by escaping neutrons and gamma rays at the instant of the explosion. The remaining energy of the atomic bomb appears over an extended period of time in the form of gamma and beta radiation from the fission products remaining after the atomic explosion. Because of natural radioactive decay, the activity of the fission products falls off or decays in the course of time.

Chapter 3

CHARACTERISTICS OF AN AIR BURST

DESCRIPTION OF AN AIR BURST

Introduction

3.01. In military operations, the atomic bomb may be exploded in the air, on the surface, or under the surface of ground or water. The effects would be different in each case, so the characteristics of various types of bursts will be considered separately. This chapter will deal with an air burst, while other bursts will be described in chapter 4. For purposes of discussion, an air burst may be defined as one in which the atomic bomb is exploded at an altitude of more than 500 feet.

The Ball of Fire

3.02. Within a few millionths of a second of the explosion of an atomic bomb in air, there is formed an intensely hot, luminous sphere of compressed gas. This is called the *ball of fire* (fig. 3.02). After the lapse of about a ten-thousandth part of a second, its brightness is such that at a distance of 10 miles it would appear to be more than 30 times as brilliant as the sun at noon. Thus, in one of the test explosions at Nevada in 1951 the glare in the sky, in the early hours of the dawn, was visible over 400 miles away.

3.03. As it cools, the ball of fire increases in size and becomes less bright. At the same time it rises, like a hot-air balloon. At about 1 second after the explosion of a nominal (20-kiloton TNT energy equivalent) atomic bomb, the ball of fire has reached its maximum size. It is then about 300 yards across, and is rising at the rate of 150 to 300 feet per second. After 10 seconds, when the ball of fire has cooled to such an extent that it is no longer visible, it has risen to something like one-third of a mile from the point of burst.

Formation of Smoke Cloud

3.04. While the ball of fire is still visible, the temperature, at least in the interior, is so high that all the substances present are in the form of vapor. This will include the radioactive fission products and uranium or plutonium which has escaped fission, as well as the casing material of the bomb. As the temperature falls, the vapor will condense to form a smoke.

3.05. Depending on the height of the air burst of the atomic bomb and on the nature of the terrain, a strong updraft with inflowing winds will occur in the immediate vicinity. These, together with the air blast created by the explosion, will suck up dust and other debris from the earth's surface.

3.06. There is consequently formed an expanding and rising column of smoke. It consists of very small radioactive particles of the fission products, of residual fissionable material, and of dust. The proportion of the latter will depend on the height of the explosion and the nature of the surface below. If the air is moist, the column may also contain drops of water.

3.07. The rate at which the radioactive smoke or the cloud column ascends varies with the meteorological conditions. In general, it will reach a height of 1 mile in 20 seconds after the explosion, 2 miles in 50 seconds, and 3 miles in a little over $1\frac{1}{2}$ minutes. The height to which it rises depends on the energy of the bomb and on the temperature gradient and density of the atmosphere. When the cloud attains a height where the density of the gases is the same as that of the surrounding air, usually upon reaching the base of the stratosphere, it will cease to rise and the top of the cloud will spread out for a distance of several miles. This forms the head of the characteristic mushroom-shaped cloud, the smoke column being the stem (fig. 3.07). Portions of the column may also spread out in different directions at lower altitudes, depending on the wind velocity at the various levels.

3.08. Within about 10 minutes or so the mushroom cloud attains its maximum altitude of from 5 to 8 miles, or more, depending on circumstances. It remains visible for about an hour until it is dispersed by the winds into the surrounding atmosphere and merges with other clouds in the sky.

The Shock Wave

3.09. At roughly a thousandth of a second after the explosion, a high-pressure wave develops and moves outward from the ball of fire. This is the shock wave, to be described more fully below, which

Figure 3.02. The ball of fire formed in an air burst.

Figure 3.07. The mushroom-shaped cloud characteristic of many atomic air bursts.

is the cause of the destructive blast accompanying an air burst. The high-pressure front of the shock wave travels rapidly away from the bomb, and after the lapse of 1 second, when the ball of fire has attained its maximum size, the shock front is some 500 yards further ahead. At 10 seconds after the explosion the ball of fire is no longer visible, and the shock wave has traveled more than 2 miles. It is then moving at about 1,150 feet per second, that is, slightly faster than the speed of sound.

3.10. When the shock wave strikes the surface of the earth, it is reflected back. This reflected shock wave is also capable of causing material damage. At a certain point, which depends chiefly on the height of burst and the energy of the explosion, the direct and reflected shock waves fuse. This fusion phenomenon is called the *Mach effect*. In the case of the air burst of a nominal atomic bomb at an altitude of 2,000 feet, the Mach effect sets in when the shock front is about 700 yards from ground zero.[1]

3.11. Because of the fusion of the direct and reflected shock waves, the excess pressure in the fused portion, called the Mach wave (or Mach stem), is generally at least twice, and may be as much as eight times, as great as that in the direct shock wave. Consequently, the destructive effect of the explosion may be greatly enhanced. With increasing distance from ground zero, the height of the Mach wave increases, but the excess pressure, as in the direct shock wave, gradually decreases.

Thermal and Nuclear Radiations

3.12. Immediately the hot ball of fire is formed it starts to emit thermal radiation (par. 2.32), consisting of ultraviolet, visible, and infrared rays. It will be seen later that this radiation is actually sent out as two pulses. The first, lasting about one-hundredth of a second, contains a large proportion of ultraviolet rays, while the second pulse is mostly visible and infrared radiation. The latter continues as long as the ball of fire can be seen, i. e., about 10 seconds. Actually, however, most of the thermal radiation from the atomic explosion comes off in approximately 1 second, and the emission is over, for all practical purposes, within 3 seconds.

[1]*Ground zero* is the point on the ground directly below the exploding bomb.

3.13. At the instant of the explosion, the atomic bomb emits gamma rays and neutrons. In addition, nuclear radiations consisting of gamma rays, beta particles, and alpha particles are expelled by the fission products and the residual plutonium or uranium in the ball of fire and smoke cloud. Although the latter radiations will continue for some time, only the gamma radiation will reach the earth's surface in appreciable amounts during the first minute, with about half arriving in the first second. By the end of a minute the atomic cloud will have reached a height of over 2 miles, as seen in paragraph 3.07, and nearly all the nuclear radiation will be absorbed in the intervening air.

Chronological Development of the Air Burst

3.14. Since it is important, from the defense standpoint, to understand clearly how the characteristics of an atomic explosion, namely—shock (or blast), thermal radiations, and nuclear radiations, are related with respect to time, a series of drawings are appended (figs. 3.14a to e). These show the development of the phenomena associated with an air burst. It should be realized that the drawings are schematic only, and do not represent what can be seen. All the eye can see, if not blinded by the brilliance, is the ball of fire and the smoke column and cloud. The shock front is not visible, although the blast can be felt. The skin is sensitive to the thermal radiation, but none of the human senses can detect the nuclear radiations.

BLAST CHARACTERISTICS

Properties of the Shock Wave

3.15. In the preceding sections the three characteristics of an air burst, namely—blast, thermal radiation, and nuclear radiation, were considered mainly with respect to the time factor. In the following portions of this chapter these characteristics will be treated in more detail, with the purpose of explaining the part each plays in the effects of an atomic explosion.

3.16. It was seen in chapter 2 that the heated and compressed gases formed by an exploding bomb soon begin to move outward from the bomb, and in doing so exert a considerable pressure on the surrounding medium. As the gases from the bomb

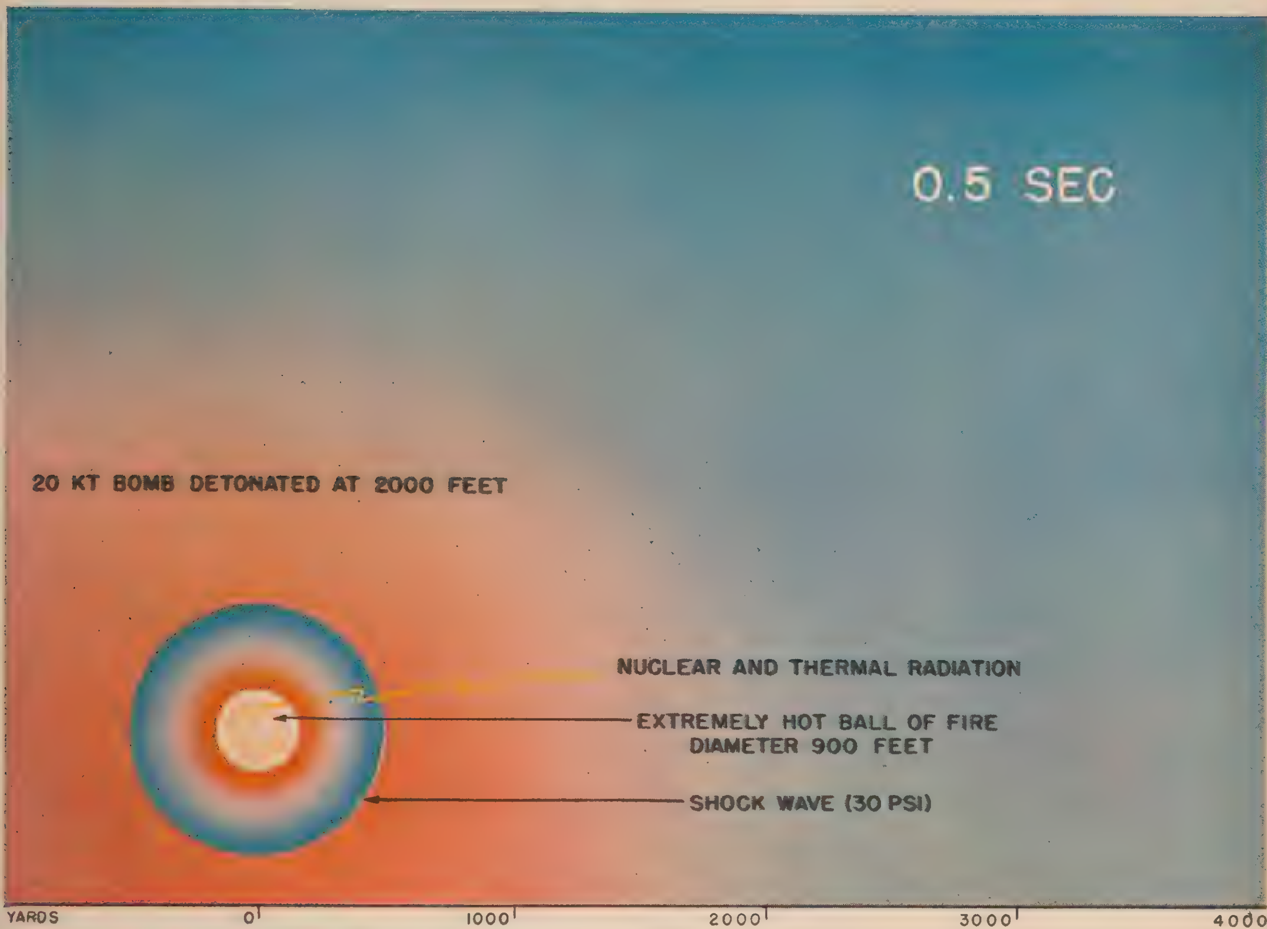


Figure 3.14a. Chronological development of an atomic air burst: 0.5 second after detonation.

Almost at the instant of detonation of an atomic bomb in the air, an intensely hot and luminous ball of fire forms. Due to its very high temperature, it emits thermal radiation capable of causing burns of exposed skin at a distance of 2 miles on a clear day. The explosion process and the radioactive decay of the resulting fission products are accompanied by nuclear radiations which are also emitted from the ball of fire. These radiations can cause injury to unprotected persons up to a mile or so away.

Very soon after the explosion a destructive shock or blast wave develops in the air and moves away from the ball of fire. At 0.5 second after the explosion of a "nominal" (20-kiloton TNT equivalent) atomic bomb in the air, the ball of fire has nearly attained its maximum size of 300 yards across. The shock wave has progressed roughly 250 yards ahead of the ball of fire, as indicated in the figure. The overpressure in the shock front, that is, the pressure in excess of the normal atmospheric pressure of 14.7 psi, is about 30 psi. For an air burst at a height of 2,000 feet, this shock wave will not have reached the ground by the end of 0.5 second.

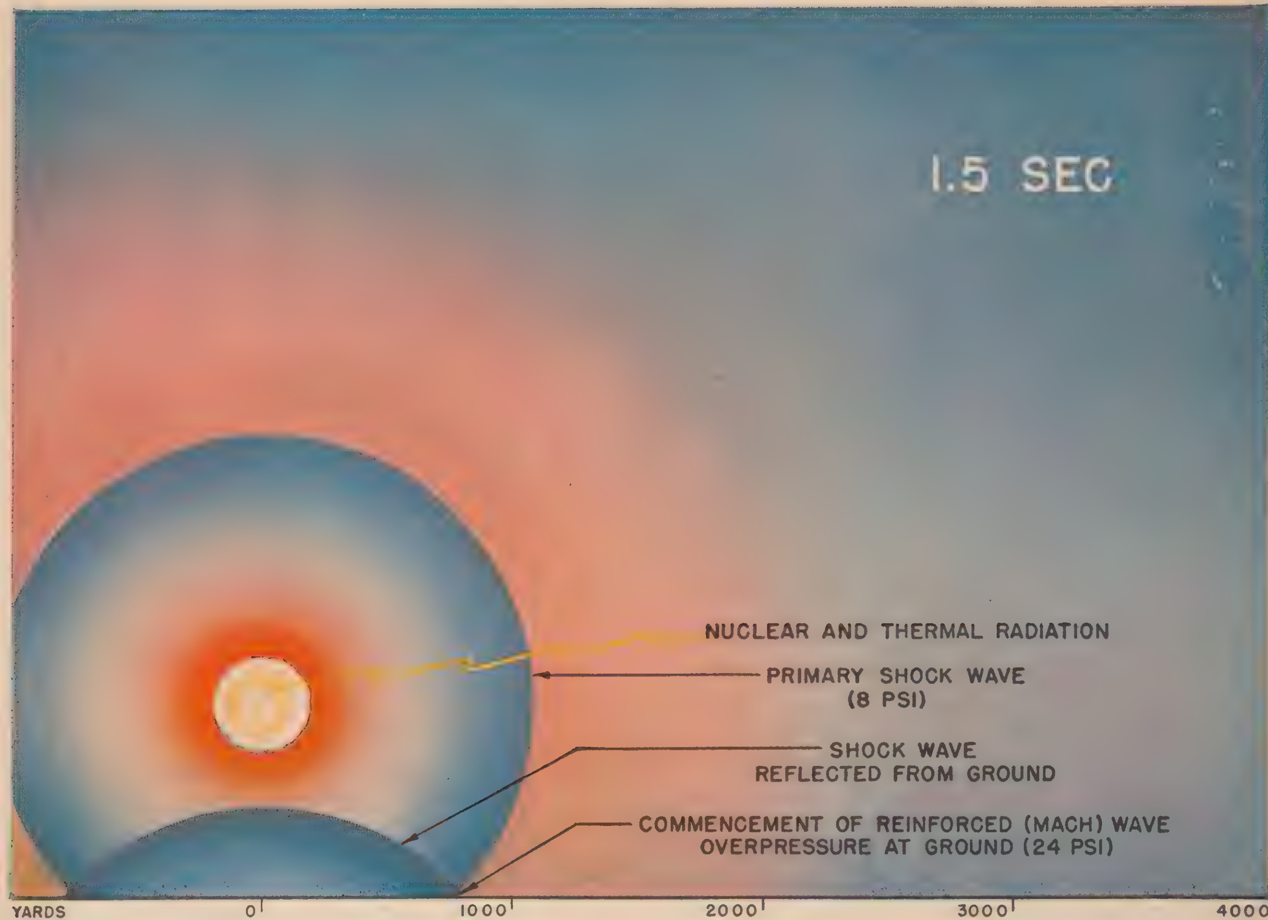


Figure 3.14b. Chronological development of an atomic air burst: 1.5 seconds after detonation.

The shock wave touches the earth's surface at about 0.7 second after the explosion and continues to move outward at a rate of roughly one-third of a mile per second (20 miles per minute). When this primary shock wave strikes the ground, another shock wave is produced by reflection. At a certain point, which depends upon the height of burst and the energy of the bomb, the primary and reflected shock waves fuse near the ground to form a reinforced wave, called the Mach wave. For the explosion of a nominal atomic bomb at an altitude of 2,000 feet, the fusion commences at about 1.5 seconds after the detonation. The shock front is then about 1,050 yards from the center of the explosion, or 750 yards from ground zero, as seen in the figure. The overpressure at the front of the primary shock wave in the air is 8 psi, but that of the reinforced Mach wave at the ground level is 24 psi. The fusion of the primary and reflected shock waves has thus resulted in a three-fold increase in the pressure of the air blast on the ground. Hence the Mach effect considerably enhances the destructive effect of the explosion.

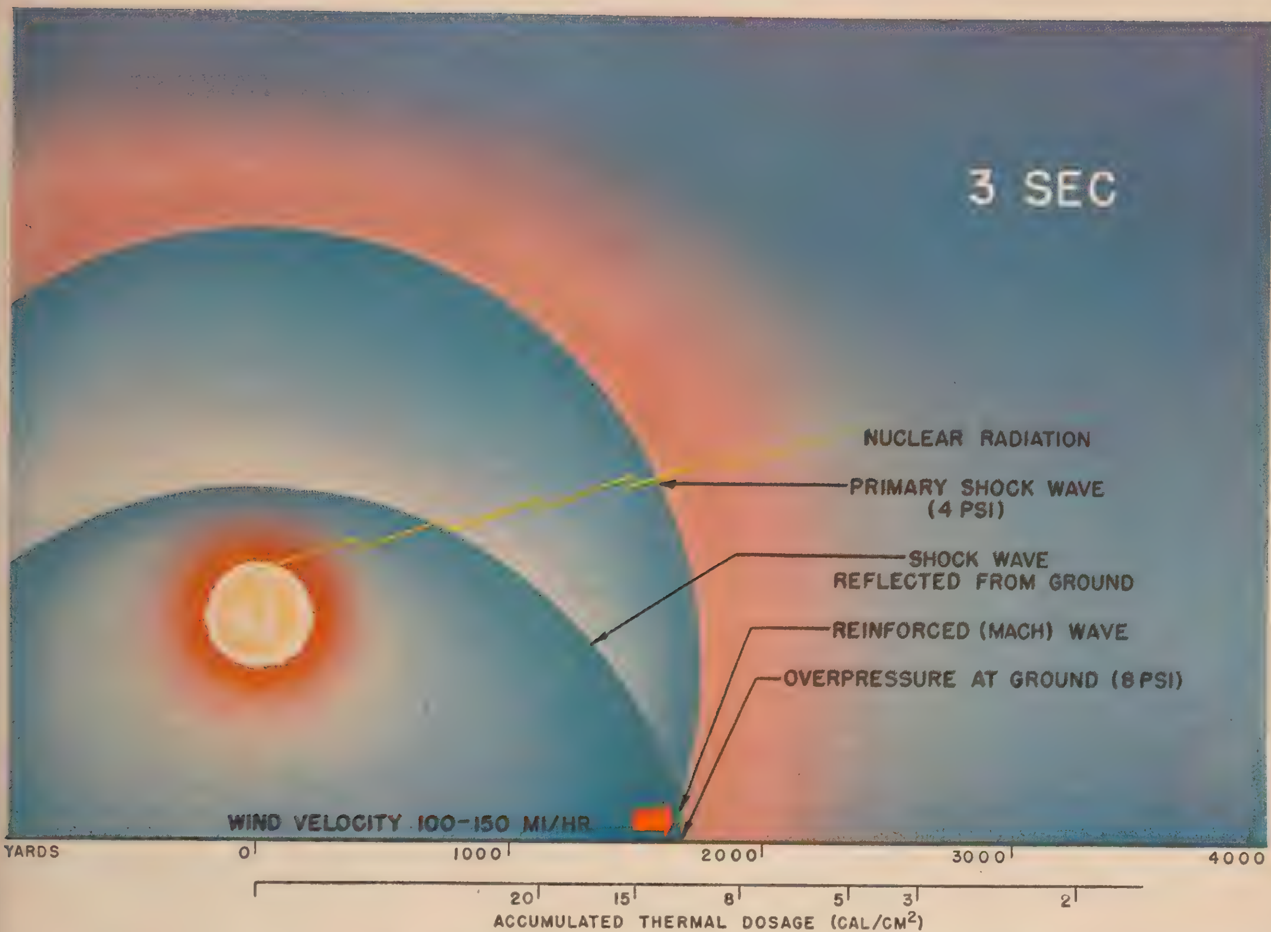


Figure 3.14c. Chronological development of an atomic air burst: 3 seconds after detonation.

As time progresses, the Mach wave front increases in height and moves outward, so that by the end of 3 seconds after the explosion it is more than 1,600 yards from ground zero. The overpressure on the ground at the front of the Mach wave is about 8 psi, compared with 4 psi of the primary shock wave in the air. The wind velocity on the ground is 100 to 150 miles per hour, and the air blast has considerable destructive potential.

The interior of the ball of fire is still very hot at 3 seconds after the explosion, but the surface has cooled to such an extent that the thermal radiation is no longer significant. Nuclear radiation, however, from the ball of fire continues to reach the ground.

The total accumulated doses of thermal radiation, expressed in calories per sq. cm., received at various distances from ground zero on a moderately clear day, are shown on the scale below the figure.

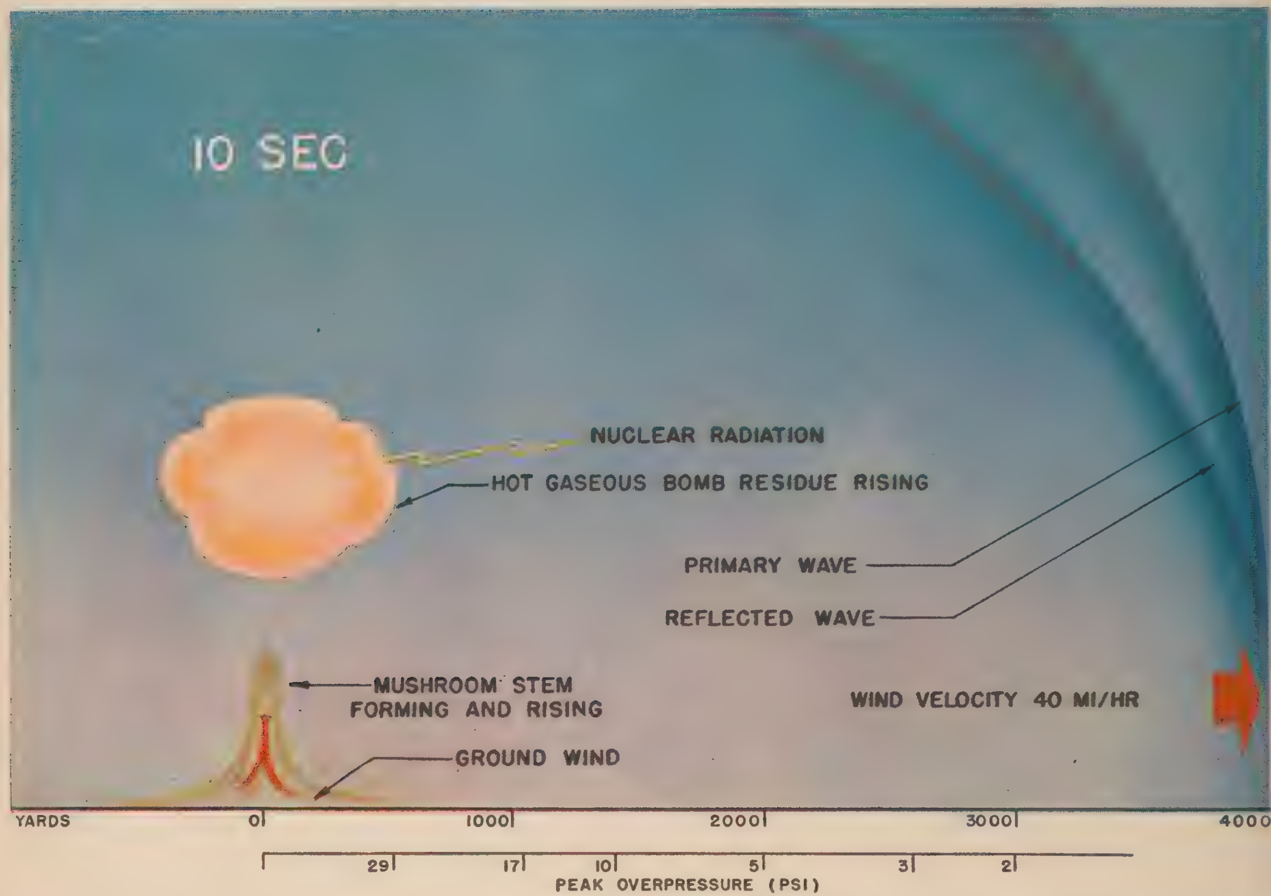


Figure 3.14d. Chronological development of an atomic air burst: 10 seconds after detonation.

After 10 seconds, the shock wave has progressed nearly $2\frac{1}{2}$ miles from ground zero. Although the wind velocity near the ground is about 40 miles per hour, the overpressure at the front of the Mach wave is only about 1 psi. Consequently, apart from plaster damage and window breakage, the destructive effect of the shock wave is essentially over.

The ball of fire is now no longer luminous. However, it is still very hot, so that the gaseous residue from the bomb behaves like a hot-air balloon, rising at the rate of about 220 feet per second (150 miles per hour). As it rises, it causes air to be drawn inward and upward, somewhat similar to the updraft of a chimney. This produces a ground wind which raises dirt and debris from the earth's surface to form the stem of what will eventually be the characteristic mushroom cloud.

The scale at the bottom of the figure shows the maximum or peak values of the overpressure on the ground attained in the shock wave during its outward motion.

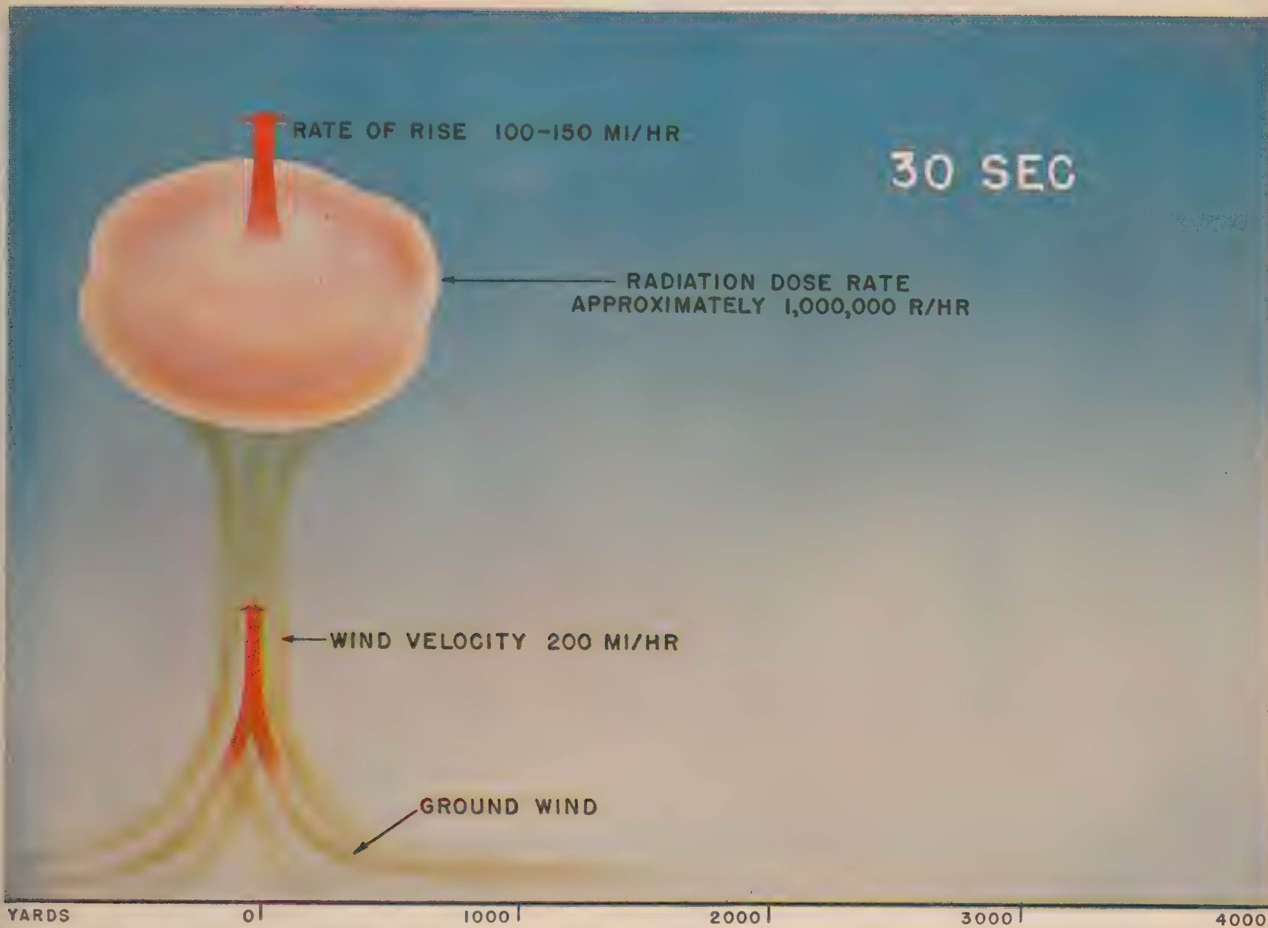


Figure 3.14e. Chronological development of an atomic air burst: 30 seconds after detonation.

The hot residue of the bomb continues to rise, at a rate of 100 to 150 miles per hour. At the same time it expands in size and cools. As a result the gaseous fission products, and other bomb residues, condense to form a cloud of highly radioactive particles. However, because of the distance above the earth's surface, and the decay of the activity, only a small quantity of nuclear radiation now reaches the ground. In fact, at 30 seconds after the explosion about 95 per cent of the total amount of the immediate nuclear radiation capable of reaching the ground will have been received. Flying through the atomic cloud at this time would, of course, represent a serious radiation hazard, as is indicated by the dose rate of about a million roentgens per hour.

The ground wind and updraft, referred to under figure 3.14d, continue to raise dirt and debris which will form the stem of the mushroom cloud. Within about 10 minutes, the cloud may rise to a height of 5 to 8 miles, and then the top will spread out to form the characteristic mushroom head. Ultimately, the radioactive particles in the cloud will be dispersed by the wind and, except under special weather conditions, there will be no appreciable hazard on the ground.

Figure 3.16. The ball of fire, touching the ground, and the shock front produced in the test atomic explosion at Alamogordo, N. M. An earlier photograph of this same burst is shown in figure 4.71.

continue to expand and push away more and more air, the later portions move through a region that has been compressed and heated by the earlier motion of the air. Consequently, the following (or inner) parts of the compression wave travel faster than, and eventually catch up with, the leading (or outer) part. The result is the formation of what is known as a *shock wave*, its front, called the *shock front*, behaving like a moving wall of highly compressed air (fig. 3.16). The shock wave, with its front of high pressure, and the accompanying winds, are responsible for the blast damage caused by an air burst.

3.17. In considering the destruction caused by the shock wave, the important quantity is the excess pressure over that of the atmosphere. This excess pressure is called the *overpressure*. It is highest at the shock front and falls off toward the region of the explosion. The maximum pressure at the shock front is called the *peak overpressure*. It is the peak overpressure of the shock wave which largely determines the degree of destruction caused by an atomic explosion in the air.

3.18. As the shock front moves outward, the overpressure of the front decreases, as indicated in figure 3.14a, b, c. The destructive effect of the shock wave thus decreases with increasing distance from the bomb. The values of the peak overpressure in the air at various distances from the explosion of a nominal atomic bomb are represented by the curve in figure 3.18. The overpressures are expressed in pounds per square inch, abbreviated to psi; normal (or standard) atmospheric pressure at sea level is 14.7 psi. It should be noted that the distances are those from the actual point of burst, i. e., the slant ranges, and not from ground zero.

3.19. The overpressures have been calculated on the assumption that the explosion takes place in free air, that is to say, at such a distance from the surface of the earth that there is no appreciable re-

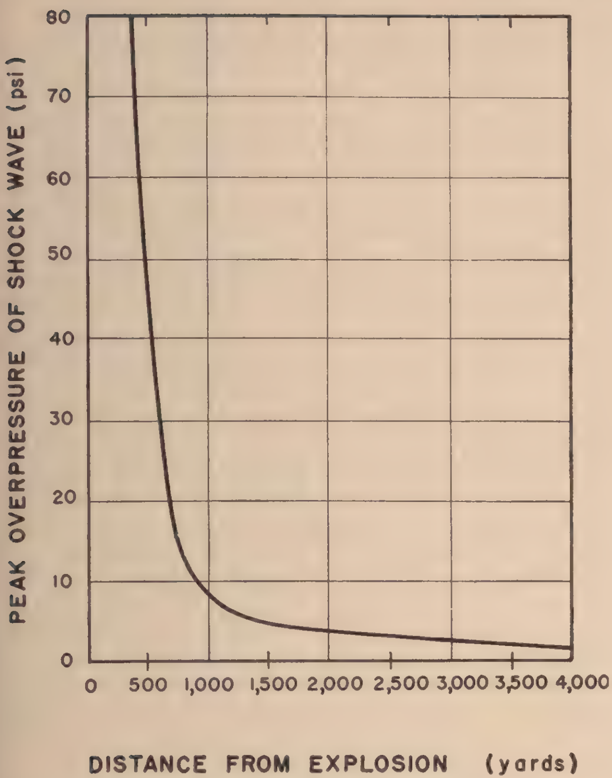


Figure 3.18. The variation of the peak overpressure with distance from an atomic explosion in free air.

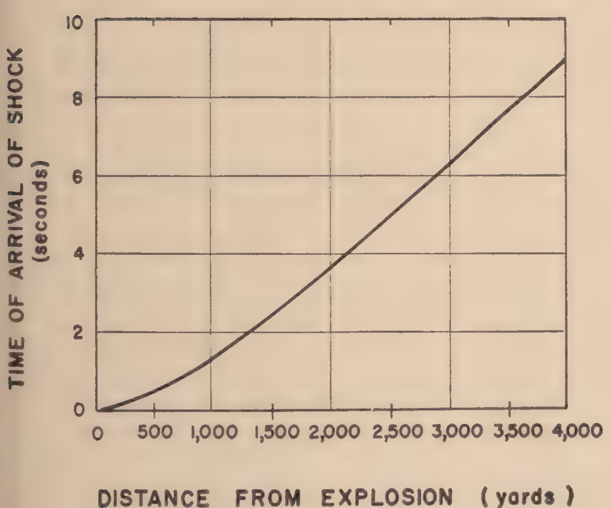


Figure 3.20. Time of arrival of shock front at various distances from an atomic explosion in the air.

flection of the shock wave. Strictly speaking, therefore, figure 3.18 gives the shock overpressure which would be experienced by aircraft flying at approximately the same altitude as that at which the burst occurred. However, by allowing for reflection of the shock wave and the Mach effect, the actual peak overpressures on the ground can be determined (see par. 3.27).

3.20. An indication of the rate at which the shock front travels is given by figure 3.20, where the time of arrival of the shock is plotted against the distance from the bomb. Thus, from figures 3.18 and 3.20 it is possible to estimate the peak overpressure of the shock wave and the time at which it reaches a point at a specified distance from the bomb. The results for various distances from the bomb are summarized in table 3.20; the maximum velocity of the blast wind which accompanies the passage of the shock wave is also given in each case.

Table 3.20. Characteristics of Shock Wave from Nominal Atomic Bomb in Free Air

Distance from explosion (yards)	Time of arrival of shock front (sec.)	Peak overpressure (psi)	Wind velocity (mph)
500	0.5	25	690
1,000	1.4	8.0	270
2,000	3.8	2.7	96
3,000	6.3	1.8	60
4,000	9.0	1.5	40

Positive and Negative Phases

3.21. When the shock front has traveled a certain distance, roughly 400 to 500 yards, the pressure behind it falls so rapidly that it is actually lower than that of the surrounding atmosphere. In other words, a partial vacuum is produced in the later parts of the shock wave, and air is sucked in instead of being pushed out. This is the *rarefaction* or *suction phase* of the wave. It is sometimes called the negative phase to distinguish it from the positive or compression phase. During the positive phase the wind moves away from the explosion, and in the negative phase its direction is reversed. Because of the higher pressures, the blast wind has a higher velocity in the positive phase than in the negative phase. It is consequently in the compression phase of the shock wave that most of the blast damage occurs (fig. 3.21).

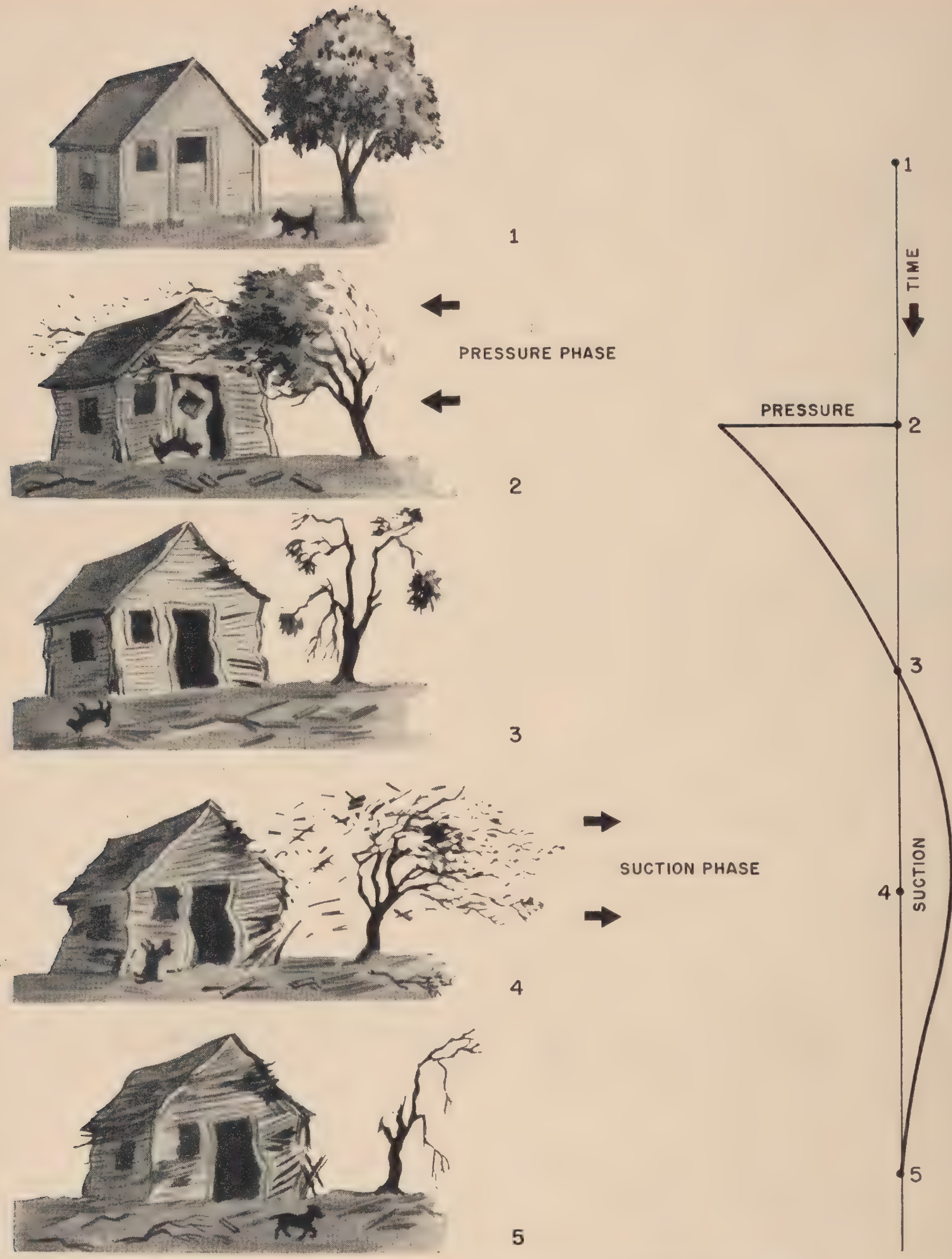


Figure 3.21. Representation of compression and suction phases in a shock wave and their effects.

3.22. At a specified distance from the explosion, the change of pressure with time will be as depicted at the right of figure 3.21. For a short interval after the air burst there will be no increase in pressure; then, when the shock front arrives, the pressure will suddenly increase to a large value, namely—the peak overpressure considered above. Subsequently, the pressure will fall rapidly until it sinks below that of the atmosphere; it then rises slowly until ordinary atmospheric pressure is established.

3.23. The positive phase of the shock wave at 1 mile from the air burst lasts for approximately seven-tenths of a second. The duration varies with distance but is much the same for all regions of interest, that is, up to 2 miles or so from the burst. It is because the shock wave from an atomic explosion acts for this relatively long period of time that the atomic bomb is especially destructive.

Mach Effect and Height of Burst

3.24. It was mentioned in paragraph 3.10 that at a certain distance from an atomic air burst the direct shock wave can fuse with the shock wave reflected from the earth's surface to cause the Mach effect. This results in a multiplication of the total overpressure on the surface due to an air burst at moderate altitudes, and hence the destructive force of the blast wave on buildings or ships is increased.

3.25. The Mach effect is particularly important in connection with the air burst of an atomic bomb because the multiplying effect is generally greater the higher the pressure of the shock wave. Thus, for a strong shock, that is, for a shock wave of high pressure, the overpressure in the Mach wave may be as high as eight times the overpressure in the direct wave. Even for a weak shock, the Mach effect may more than double the overpressure. It is evident, therefore, that the destruction caused by the atomic bomb can be greatly enhanced by taking advantage of the multiplication in pressure due to the Mach effect.

3.26. The overpressure in the direct wave decreases as it moves further from the target, and so the Mach multiplication decreases correspondingly. Consequently, the advantage gained from the Mach effect decreases with distance from the burst. An important factor in determining the over-all destruction caused by the bomb is thus the height of burst. A low burst, with greater overpressures on the ground, would give greater multiplication due to the Mach effect. On the other hand, a burst that is too low, is wasteful because of the overdestruction it causes near ground zero (par. 4.76).

3.27. Calculations have shown that for a nominal atomic bomb a height of burst of about 2,000 feet will cause maximum damage on the ground in a modern city. This was roughly the altitude at which the bombs were detonated in the attacks on Hiroshima and Nagasaki. The estimated peak overpressures *on the earth's surface* at various distances from ground zero, due to a nominal atomic bomb exploding at 2,000 feet, are shown in figure 3.27. The curve may be compared with that of figure 3.18 which gives the overpressures produced by the direct shock wave, disregarding reflection at the surface.

3.28. The Mach effect sets in at about 700 yards from ground zero, where there is seen to be a bend in the curve in figure 3.27. In this region the multiplication of pressure due to reflection has its largest value, a factor of nearly three in this case. At greater distances from ground zero, the multiplication falls off to a factor of somewhat more than two. Thus, at 1 mile from ground zero, the peak overpressure is then roughly 7 psi, for a height of burst of 2,000 feet, compared with about 3 psi in the direct shock wave. As will be seen in chapter 6, this difference will have a significant effect on the extent of blast damage suffered by many buildings.

3.29. If the height of burst of the nominal atomic bomb is somewhat more than 2,000 feet, the peak overpressures at and near ground zero would be less than shown in figure 3.27, because of the increased distance from the burst. At a distance of over one-half mile from ground zero, however, the pressures would be a little higher. For a height of burst of less than 2,000 feet the reverse would be true: the peak overpressures near ground zero would be greater than those in figure 3.27, but further away they would be smaller.

Scaling Rule for Blast Damage

3.30. The various data recorded above apply to the explosion of a nominal, 20-kiloton TNT energy

equivalent, atomic bomb. For a bomb having a different energy release, the appropriate results can be calculated by the use of a simple rule, often called a *scaling law.* The rule cannot be regarded as exact because it applies strictly to explosions in free air; it does not take into account the effect of the height of burst, or variations in atmospheric or terrain conditions. In spite of its approximate nature, however, the scaling law does provide a rough means of comparing the effects of bombs of different energies.

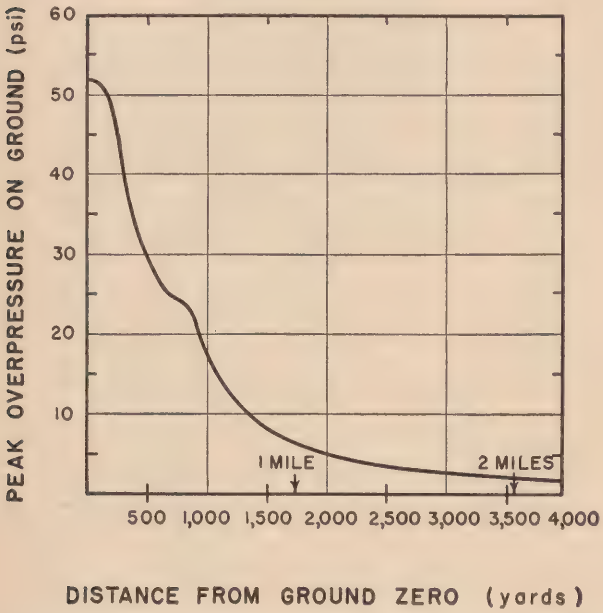


Figure 3.27. The variation of the peak overpressure on the ground with distance from ground zero, due to explosion of a nominal atomic bomb in the air at 2,000 feet altitude.

3.31. In the case of blast effects, the rule is that the distance from the explosion at which any specified overpressure is reached is proportional to the cube root of the energy release. In order to express this rule in terms of distance from ground zero, which is important in connection with damage on the earth's surface, it is necessary to know the heights of burst used for bombs of different energies. It appears probable that the height of burst which will produce maximum damage on the ground is also proportional to the cube root of the energy release. If this is the case, then the scaling rule for blast given above will apply to the distance from ground zero, as well as to the distance from the explosion.

3.32. If, for a 20-kiloton TNT energy equivalent bomb, a certain overpressure, say 5.2 psi, is reached at a distance of 2,000 yards from ground zero, then for a W-kiloton TNT energy equivalent bomb the same overpressure will be attained at a distance $(W/20)^{1/3} \times 2{,}000$ yards. If W is 40, the distance would be 2,520 yards; if W were 60, it would be 2,880 yards from ground zero. Some results calculated in this manner are recorded in table 3.32 and represented graphically in figure 3.32. The distances from ground zero are given at which the peak overpressures on the surface are 25, 5, and 3 psi, respectively, for the air burst of bombs of 20, 40, 60, and 100 kiloton TNT energy equivalent. It is seen that the distance from ground zero at which a given pressure is attained, and hence a particular type of destruction is experienced, increases less rapidly than the energy release of the bomb.

Table 3.32. Distances from Ground Zero for Specified Peak Overpressures on the Ground

Bomb energy kilotons TNT	Distances from ground zero in yards		
	25 psi Moderate damage to tanks	5 psi Moderate damage to light vehicles and electronic equipment	3 psi Light damage to vehicles and electronic equipment
20	700	2,100	2,500
40	880	2,640	3,150
60	1,000	3,030	3,600
100	1,200	3,570	4,250

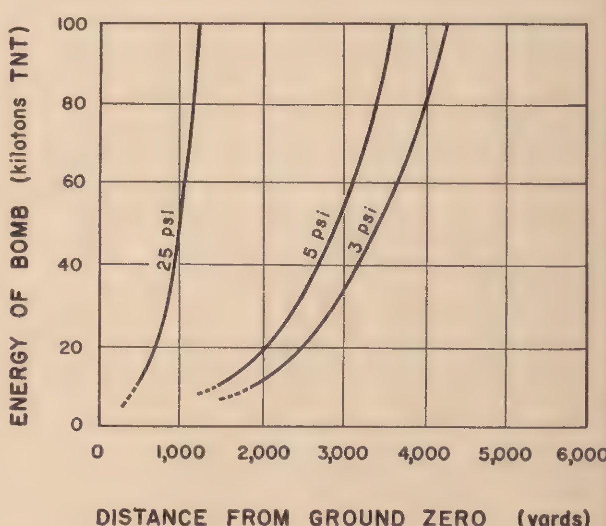


Figure 3.32. Variation with bomb energy of distances from ground zero, for specified shock overpressures on the ground.

3.33. With regard to the over-all damage and casualties, it is the area affected by the burst which is important. This is proportional to the two-thirds power of the energy release. Thus, if an air burst of a nominal atomic bomb caused damage, ranging from severe to moderate, to structures over an area of 8 square miles, then a 40-kiloton TNT energy equivalent bomb would cause the same damage over an area of $(40/20)^{2/3} \times 8 = 12.7$ square miles. For a 60-kiloton TNT energy equivalent bomb, it would be $(60/20)^{2/3} \times 8 = 16.6$ square miles. Doubling the energy release of the bomb thus increases the area of destruction by about 60 percent; while tripling the energy increases it by just over 100 percent.[2]

THERMAL (HEAT) EFFECTS

Thermal Radiation Pulses

3.34. Because of certain phenomena associated with the absorption of heat radiation by the air in front of the ball of fire, the surface temperature of the latter undergoes a curious change. While the temperature of the interior falls steadily, the surface temperature of the ball of fire decreases rapidly for somewhat more than a one-hundredth part of a second, when it reaches a minimum of 1,700° C. Then it begins to increase again until it attains about 7,000° C. at about one-third of a second, after which it falls continuously, as shown in figure 3.34. By the end of 3 seconds, the surface temperature has fallen to approximately 1,000° C.

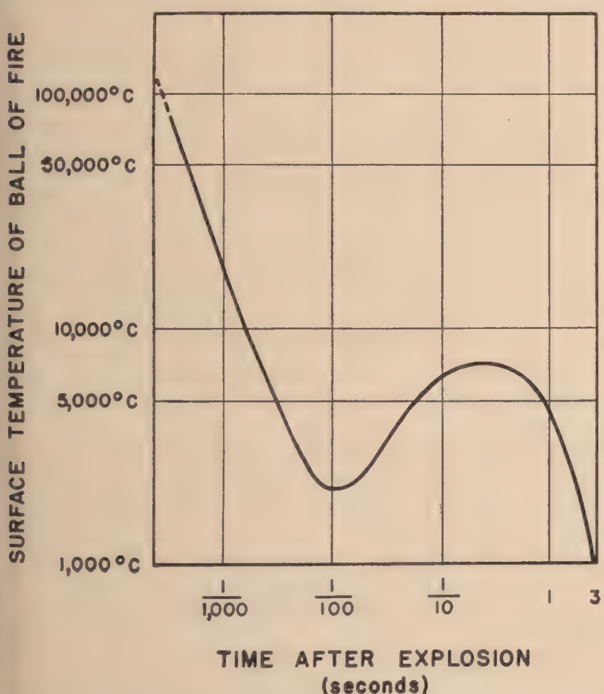


Figure 3.34. Changes in the surface temperature of ball of fire during the first 3 seconds after the air burst of a nominal atomic bomb.

3.35. It is seen that there are effectively two temperature pulses, and there are correspondingly two pulses of emission of thermal radiation from the exploding bomb (fig. 3.35). In the first pulse, which lasts for about one-hundredth of a second, the temperatures are mostly very high. As a result, much of the emitted radiation is in the ultraviolet region, but the dose delivered at a distance from the bomb is reduced due to appreciable absorption of these rays by the intervening air. Ultraviolet radiation in small doses can cause reddening of the skin, while larger doses produce painful blisters.

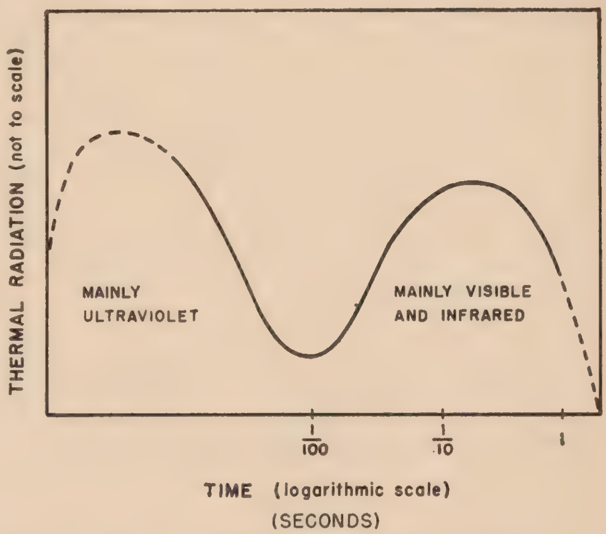


Figure 3.35. Schematic representation of the emission of thermal radiation in two pulses from an atomic air burst.

3.36 It has been estimated that the ultraviolet radiation from the first pulse could cause significant effects on the skin only within ranges at which other radiation effects are much more serious. Hence the radiation from the first pulse is primarily of academic interest.

[2]Further information on scaling is given in appendix I.

Second Pulse—Infrared Radiation

3.37. The situation is, however, quite different with regard to the second pulse. This carries almost 99 percent of the total thermal radiation energy from the atomic bomb and may last for about 3 seconds. Because the temperatures are lower than in the first pulse, most of the rays which reach the earth are in the visible and infrared parts of the spectrum. It is this radiation which is the main cause of skin burns of various degrees suffered by exposed personnel at distances up to 2 miles or more from the explosion of a nominal atomic bomb. It may also cause fires to start under suitable conditions.

3.38. In addition to the circumstance that the second radiation pulse is emitted over a period that may be as long as 3 seconds, there is another matter which is important from the defense standpoint. This is the fact that the thermal radiation, like light, travels in straight lines, and is readily stopped by moderately thick clothing. Light-colored clothing reflects the radiation and is a better protection than dark-colored clothing, which absorbs it and so tends to become hot. The radiation passes through glass but will not penetrate the walls of a building, even if they are quite thin.

3.39. Because the second radiation pulse, which is responsible for most of the thermal damage caused by an atomic air burst, may last up to 3 seconds, it might be possible to take effective evasive action. If protection from the direct radiation could be found within 1 second after the appearance of the bright light accompanying the explosion, it is possible that exposure to the heat radiation would be somewhat reduced. In some circumstances this might make the difference between a serious skin burn and a slight one. Suggestions for the type of evasive action that could be taken by personnel in the open will be given in chapter 10.

Atmospheric Reduction of Thermal Radiation

3.40. In its passage through the air, from the exploding bomb to the earth's surface, the thermal radiation undergoes a decrease in intensity. This reduction is due mainly to the molecules of the air and water, and to particles of dust, smoke, etc., in the atmosphere. It will consequently be greater on a hazy or foggy day than on a clear day. Thus, the thermal damage caused by an atomic bomb would be less when the air was hazy than if it were clear. The effect would be more pronounced at a greater distance from the explosion, because of the increased thickness of air through which the radiation travels.

3.41. The amounts of thermal energy received at various distances from ground zero, for three different states of the atmosphere, are indicated in figure 3.41. The results are for a nominal atomic bomb exploded at a height of 2,000 feet above the earth. It is seen that on an exceptionally clear day moderate skin burns would be experienced out to nearly 4,000 yards from ground zero, but on a foggy day the corresponding distance would be only 1,350 yards. On an average clear day the distance would be about 3,400 yards. A smoke screen might thus be a very effective shield against thermal radiation from an atomic explosion.

Scaling Rule for Thermal Radiation

3.42. It is reasonable to assume that the fraction of the energy liberated as thermal radiation in an atomic explosion would be approximately the same for bombs of all energies. If this is so, then the amount of thermal energy reaching a point *at a given distance from the explosion* will be directly proportional to the total energy release of the bomb. Because the height of burst may be expected to be greater the larger the energy of the bomb, the thermal energy reaching a point *at a given distance from ground zero* will, in general, increase somewhat less rapidly than the total energy release. However, to be on the safe side for defensive purposes, it may be assumed that the thermal energy received at any point at a given distance from ground zero is directly proportional to the total energy of the bomb.

3.43. The results in figure 3.41 apply to the nominal atomic bomb of 20-kiloton TNT energy equivalent. Hence, to obtain the corresponding energy delivered, at any specified distance from ground zero, for a W-kiloton TNT energy equivalent bomb, all that is necessary is to multiply the energies in figure 3.41 by $W/20$. Thus, for a 40-kiloton TNT energy equivalent bomb the energies are doubled, for a 60-kiloton TNT energy equivalent bomb they would be tripled, and so on. In general, figure 3.41 can be adapted to bombs of any specified energy release by multiplying the ordinates, that is, the total thermal energy received, by $W/20$.

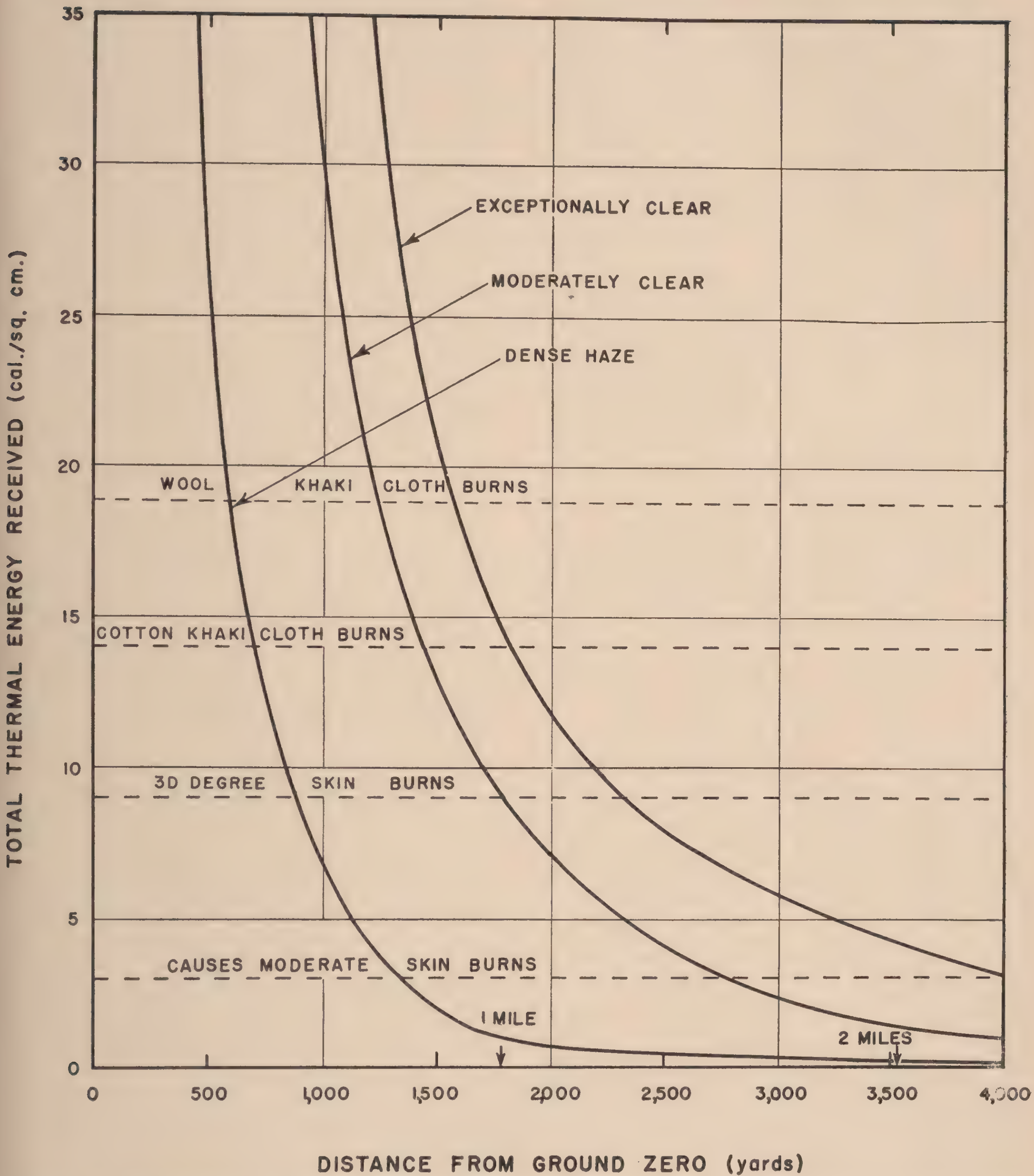


Figure 3.41. Amounts of thermal energy received at various distances from ground zero, due to a nominal atomic air burst at 2,000 feet altitude.

3.44. The calculated distances from ground zero at which certain specified amounts of thermal energy, namely, 14, 9, and 3 calories per square centimeter, would be received on a clear day, as a result of the explosion of bombs of different energy releases, are given in table 3.44 and in figure 3.44. On an exceptionally clear day the respective distances would be somewhat greater, but they would be appreciably less on a foggy day, as noted above. The effect of the state of the atmosphere is most marked for the smaller amounts of thermal energy received, as is evident from figure 3.41.[3]

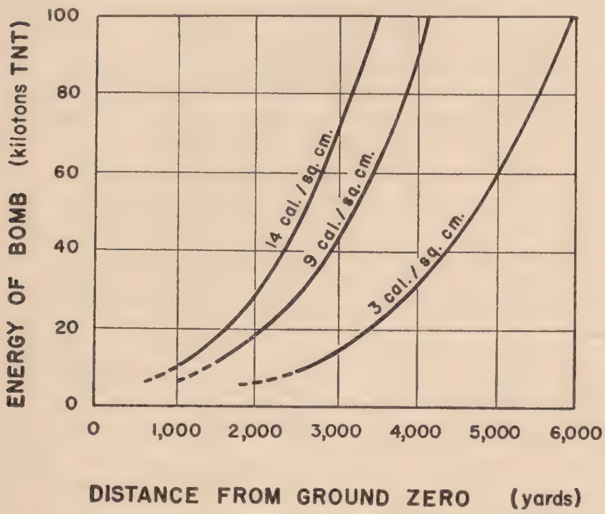


Figure 3.44. Variation with bomb energy of distances from ground zero, for specified amounts of thermal energy on an average clear day.

Table 3.44. Distances from Ground Zero for Specified Amounts of Thermal Energy

Bomb energy kilotons TNT	Distance from ground zero in yards		
	14 cal./sq. cm. Cotton cloth burns	9 cal./sq. cm. Causes severe skin burns	3 cal./sq. cm. Causes moderate skin burns
20	1,650	2,150	3,400
40	2,380	2,850	4,300
60	2,750	3,450	5,000
100	3,500	4,100	6,000

3.45. It is seen from table 3.44 that while a 20-kiloton TNT energy equivalent bomb would produce moderate skin burns out to 3,400 yards from ground zero on an average clear day, a 40-kiloton TNT energy equivalent bomb would extend the range to 4,300 yards, and a 60-kiloton TNT energy equivalent bomb to 5,000 yards from ground zero. A three-fold increase in the energy release of an atomic bomb would thus increase the range for moderate skin burns by about 40 percent. However, the effective area, which is the important matter from the standpoint of the total number of casualties, is related to the square of the distance. This increases by nearly 60 percent when the bomb energy is doubled, and by about 100 percent when it is tripled.

[3]Further information for the scaling of thermal radiation energy is given in appendix I.

NUCLEAR RADIATION

Immediate Nuclear Radiation

3.46. As explained in the preceding chapter the explosion of an atomic bomb is accompanied by the emission of nuclear radiations, consisting of gamma rays, beta particles, alpha particles, and neutrons. The neutrons and part of the gamma rays are emitted in the actual fission process, that is to say, simultaneously with the explosion, while the remainder of the gamma rays and the beta particles are liberated as the fission products decay. The alpha particles, on the other hand, are expelled by the uranium or plutonium which has not undergone fission in the bomb.

3.47. For defense purposes it is convenient to consider the nuclear radiation in two parts: the initial or immediate nuclear radiation and the lingering or residual nuclear radiation. The *immediate nuclear radiation* is taken as that reaching the surface of the ground (or sea) from both the ball of fire and the atomic cloud. Hence, it will include the neutrons and gamma rays given off at the instant of the explosion,[4] and the gamma rays emitted by the radioactive fission products in the rising column of smoke (see par. 3.06). It will be noted that although alpha and beta particles are present they have not been mentioned. This is because they have such short ranges that they will not reach the earth's surface after an air burst.

[4]It is believed that only a small proportion of these gamma rays succeed in getting out of the bomb. They are mostly produced before the bomb has completely blown apart and so they are largely absorbed by the bomb materials.

3.48. The effective range of the gamma rays from the fission products may be taken as about 2 miles. From above this altitude, the gamma rays reaching the earth's surface can be ignored. Thus, when the atomic cloud has attained a height of 2 miles, the danger due to the immediate nuclear radiation may be regarded as over. As seen earlier, it takes roughly a minute for the cloud to rise this distance, and so the immediate nuclear radiation from an air burst may be regarded as that emitted in the first minute after the explosion.

3.49. From observations at the time of atomic explosions, estimates have been made of the proportions of the total immediate radiation dosage received, after various time intervals, at a point on the earth's surface about 1,250 yards from ground zero in the explosion of a nominal atomic bomb at an altitude of 2,000 feet. The results are depicted in figure 3.49. The distance of 1,250 yards from ground zero was chosen because it corresponds to that at which the immediate nuclear radiation would prove lethal to about half the exposed personnel who were not protected in any way. It should be remembered, in this connection, that clothing offers negligible

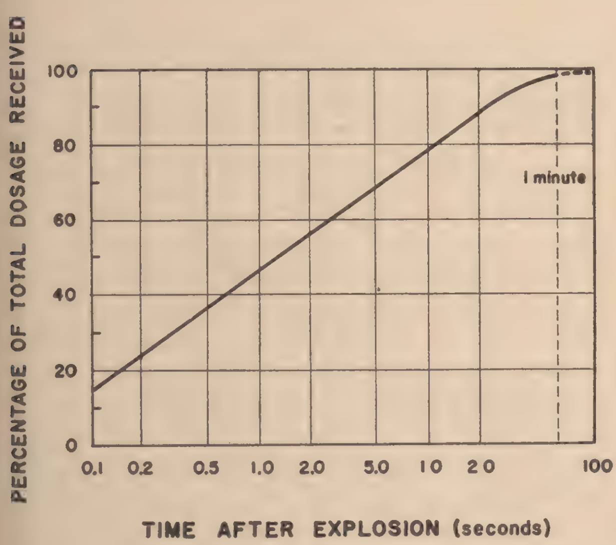


Figure 3.49. Percentage of immediate nuclear radiation received at various times after an air burst; nearly 50 percent arrives within the first second, and about 98 percent within a minute.

protection against gamma rays and walls of ordinary structures offer only limited protection unless they are of considerable thickness.

3.50. It is seen from the figure that in the air burst of a nominal atomic bomb at a height of 2,000 feet, 50 percent of the total immediate nuclear radiation arrives at a point 1,250 yards from ground zero during the first second after the explosion. Thus, by taking shelter, behind a thick barrier, or in a ditch, within 1 second of seeing the flash of the bomb, a person would avoid about half of the gamma radiation. At 1,250 yards from ground zero this might make the difference between death and moderate sickness.

Atmospheric Reduction of Gamma Rays

3.51. Gamma rays are absorbed and hence their intensity is reduced to some extent by the atmosphere. Therefore, the amount or dosage of nuclear radiation received from an atomic air burst decreases with increasing distance from the explosion. It is the general practice to express radiation dosage in terms of a unit called the *roentgen*, which gives a measure of the possible injury to personnel. In figure 3.51 are given the total gamma ray dosages, in roentgens, that reach various distances from ground zero, due to the immediate radiation from a nominal atomic bomb exploded at a height of 2,000 feet.

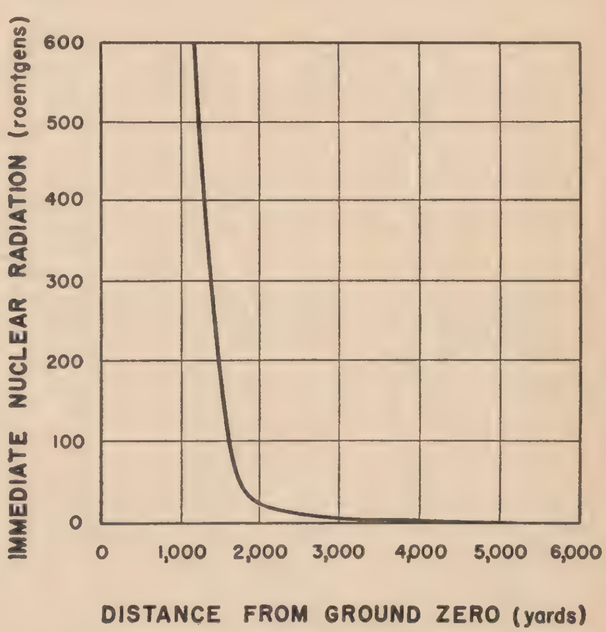


Figure 3.51. Immediate nuclear (gamma) radiation dosages received at various distances from ground zero, due to an atomic air burst at 2,000 feet altitude.

3.52. If received *over the whole body* within a short interval of time, such as would be the case for the immediate nuclear radiation, a dose of 450 roentgens will prove fatal, on the average, to about half, i. e., 50 percent, of the exposed individuals.[5] However, death will not be instantaneous, but will occur within 2 to 12 weeks after exposure. The other half will become sick, but will recover in due course. Nearly all persons receiving 600 roentgens over the whole body within a short time will die within 2 weeks of exposure. Those receiving 200 roentgens of gamma radiation may show no serious symptoms of injury for 2 or 3 weeks. About half, however, will eventually become sick, but no deaths are expected unless there are added complications (ch. 7).

3.53. It is seen from figure 3.51 that persons within 1,250 yards of ground zero from an air burst of a nominal atomic bomb at a height of 2,000 feet will receive the LD/50 (450 roentgens) or more of gamma radiation, if completely unprotected. If evasive action of some kind is taken within a second, as stated above, the total dosage received will be less than 450 roentgens, and the chance of survival will be increased. Protection of part of the body from the gamma radiation, so that the dosage is not taken over the whole body, may also mean the difference between life and death.

Scaling Rule for Immediate Nuclear Radiation

3.54. It can be assumed that the energy of the immediate nuclear radiation increases roughly in proportion to the total energy release of the atomic bomb. In this event, the total radiation dosage received at a given point will also be approximately proportional to the energy release. Consequently, for an atomic bomb of W-kilotons TNT energy equivalent, the dosage received at any given distance from ground zero should be multiplied by $W/20$.

3.55. In table 3.55 and figure 3.55[6] are recorded the approximate distances from ground zero at which 600, 450 and 200 roentgens, respectively, would be received at a completely unprotected position, due to the immediate nuclear radiation from air bursts of atomic bombs of different energy releases. A comparison of the results in this table with those in tables 3.32 and 3.44 (see also figs. 3.32, 3.44, and 3.55) shows that as the energy of the bomb is increased the effective range of the immediate nuclear radiation does not increase as rapidly as does the effective range for blast and for thermal radiation. Thus, five-fold increases of the bomb's energy from 20- to 100-kiloton TNT equivalent, increases the effective range of the immediate nuclear radiation by roughly 30 percent, but the range for blast damage or for thermal radiation injury increases by about 70 percent. The hazard due to immediate nuclear radiation consequently becomes relatively less important, as compared with other hazards, with increasing energy of the atomic bomb.[7]

Table 3.55. Distances from Ground Zero for Specified Amounts of Immediate Nuclear Radiation

Bomb energy kilotons TNT	Distance from ground zero in yards		
	600 Roentgens Lethal to most individuals if received over whole body	450 Roentgens Lethal to about 50 per cent (LD/50)	200 Roentgens 50 percent will become sick but no deaths expected
20	1,190	1,250	1,440
40	1,340	1,410	1,600
60	1,440	1,500	1,700
100	1,550	1,620	1,870

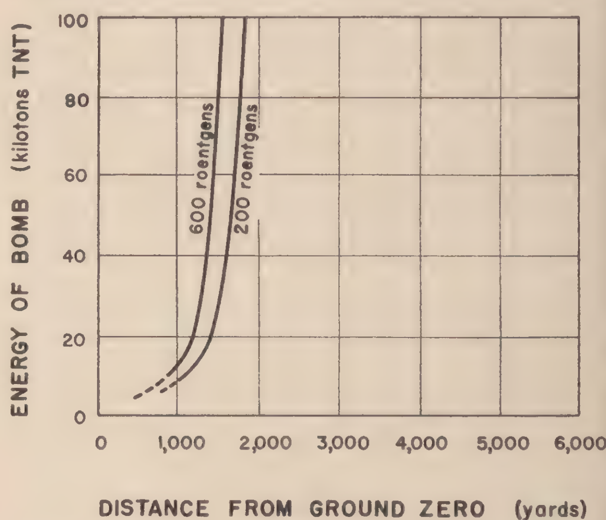


Figure 3.55. Variation with bomb energy of distances from ground zero, for specified amounts of immediate nuclear radiation.

[5]The radiation dose which is expected to prove lethal to 50 percent of exposed individuals is called the "LD/50." It is sometimes referred to as the "median lethal dose," but this is not strictly correct.

[6]The curve for 450 roentgens has been omitted from the figure as it is so close to that for 600 roentgens.

[7]Further information for the scaling of nuclear radiation is given in appendix I.

Lethal Range of Neutrons

3.56. Although a considerable number of neutrons are emitted by the exploding bomb, they were neglected in the foregoing estimates of radiation dosage. The reason is that in the case of an air burst at an altitude of 2,000 feet, only a small proportion of the neutrons reach the earth's surface. There is not sufficient information yet available to make possible exact estimates, but it would appear that the lethal range of neutrons from a nominal atomic bomb is about 500 yards, and certainly not more than 700 yards from ground zero. At these distances, the gamma ray dosage is several thousand roentgens, and would be fatal to unprotected personnel.

3.57. At 1,250 yards from ground zero, where the total dosage due to gamma rays from the immediate nuclear radiation is 450 roentgens, the neutron intensity will be well below the lethal range. It would seem, therefore, that the neutrons represent a negligible hazard as compared with that due to the gamma rays. Consequently, from the point of view of defense, the contribution of the neutrons to the immediate nuclear radiation can be ignored.

3.58. The conclusion reached above will also apply for bombs of higher energy release than the nominal atomic bomb. The lethal range for neutrons is always considerably less than the LD/50 range for the immediate gamma radiation. As is the case with the latter, increasing the energy release of the bomb has a relatively small effect on the lethal range of the neutrons.

Alpha and Beta Particles

3.59. As stated at the beginning of this section, although the immediate nuclear radiation does include beta particles from the fission products and alpha particles from the bomb material which has not suffered fission, these particles would not reach the ground. Very few beta particles can travel more than 3 or 4 yards in air before being absorbed, while alpha particles are stopped in a few inches. Hence, all the alpha and beta particles are absorbed within a short distance of the atomic cloud, and so they do not contribute to the immediate nuclear radiation hazard. This would be true irrespective of the energy release of the bomb.

RESIDUAL NUCLEAR RADIOACTIVITY

Sources of Residual Activity

3.60. The residual radioactivity is that which remains after the immediate effects of the explosion are over. It consists of gamma rays and beta particles from the fission products and of alpha particles from uranium or plutonium which has escaped fission in the bomb. In addition, there is a possibility that the neutrons in the immediate radiation may convert harmless substances on the ground into radioactive materials capable of emitting gamma rays and beta particles for a considerable period of time. This latter phenomenon is referred to as *induced radioactivity*. It should be noted that in an atomic explosion it is only the neutrons that are capable of causing induced radioactivity; the gamma rays have no such effect.

The Fall-Out

3.61. When the radioactive particles of fission products and fissionable material in the atomic cloud (par. 3.06) collide with particles of dirt, which are generally larger, they may adhere. Consequently, if there are any dirt particles in the cloud, they may become contaminated with radioactivity. When the violent disturbance due to the exploding bomb has subsided, and the mushroom cloud has dispersed, the radioactive particles will gradually fall back to earth. This effect is referred to as the *fall-out*. It is because it represents a possible hazard that the fall-out must be considered.

3.62. In the case of an air burst, however, the particles become widely dispersed and the quantity falling in any moderate-sized area will be very small. Consequently, the fall-out will be a negligible hazard. At Hiroshima and Nagasaki, for example, casualties ascribable to the fall-out were completely absent.

3.63. Special circumstances might arise in which there would be some radioactive fall-out even with an air burst. If rain were to fall at the time of, or very soon after, the explosion, the raindrops would carry down with them some of the radioactive particles. Such was the case, for example, in Test Able at Bikini (par. 1.16). Within 2 or 3 hours of the explosion, light rain showers developed at sea in the vicinity, and the raindrops were radioactive. The

extent of the activity was, however, very small and would not have been of military significance.

Neutron-Induced Radioactivity

3.64. In the event of an air burst at a height of 2,000 feet or more, the number of neutrons reaching the ground would not be sufficient to produce any large amount of induced radioactivity. Further, not all substances become radioactive when exposed to neutrons. Of the common elements in which radioactivity can be induced by neutrons, the most important is sodium. It may be noted in this connection that soap left on a few of the target vessels in Test Able at Bikini was found to be slightly radioactive after the explosion. This was due to the neutron-induced activity in the sodium present in the soap. Some radiation, also attributable to radioactive sodium, was detected on the surface of the lagoon, but because of the rapid decay it was not very significant.

3.65. It is reported that some of the bodies found near ground zero at Hiroshima were mildly radioactive, probably because of exposure to neutrons. The induced activity was, however, so small that there was no health hazard to those treating the injured or removing the dead. It is of interest to mention, in this connection, that the normal human body always contains appreciable amounts of radioactive carbon and potassium, which expel both beta particles and gamma rays. The mere presence of radioactivity in the body is thus not to be regarded as a danger to life.

SUMMARY

The air burst of an atomic bomb is accompanied by the formation of an intensely hot, luminous sphere of compressed gas called the ball of fire. As this ascends and cools, an expanding column of smoke forms and rises to a height of from 5 to 8 miles before spreading out to produce the characteristic mushroom-shaped atomic cloud.

The explosion is followed by the formation of a shock wave, moving outward at high speed. The overpressure in the shock wave and the accompanying wind are responsible for the blast damage to structures. At a certain distance from ground zero, the direct shock wave fuses with the wave reflected from the surface, causing the Mach effect. The overpressure at the surface is thereby greatly increased.

Thermal radiation is emitted from the ball of fire in two pulses. The first lasts for little more than a one-hundredth part of a second and contains a large proportion of ultraviolet radiation. The second pulse, lasting up to 3 seconds and carrying most of the thermal energy emitted by the bomb, consists mainly of visible and infrared rays. Except near ground zero, it is the second radiation pulse which is responsible for skin burns and some incendiary action.

The immediate nuclear radiation which reaches the earth from the ball of fire and the atomic cloud at the time of the explosion consists of gamma rays and neutrons. The lethal range of the neutrons is small in comparison with that of the gamma rays, and so they may be ignored.

The residual radioactivity, consisting mainly of gamma rays and beta particles from the fission products and alpha particles from the uranium or plutonium that has not undergone fission, is that which remains on the ground after the explosion. In the case of an air burst, it will usually be negligible.

Increasing the energy release of the bomb increases the effective ranges of the shock wave, the thermal radiation, and the immediate nuclear radiation, but the *area* of damage always increases less rapidly than the energy release. The effect of the immediate nuclear radiation becomes relatively less important, with respect to blast and thermal radiation, as the energy of the bomb is increased.

Chapter 4

CHARACTERISTICS OF SUBSURFACE AND SURFACE BURSTS

CHARACTERISTICS OF AN UNDERWATER BURST

Introduction

4.01. An atomic explosion under the surface of the ground or the sea will differ in certain important respects from the air burst described in the preceding chapter. The over-all damage to structures and ships due to air blast will be less for the subsurface type of burst, and the hazards due to the immediate nuclear radiation and to thermal radiation will be virtually nonexistent. But, on the other hand, the damage due to underground or underwater shock will be greater, and radioactive contamination, that is, residual radioactivity, which is negligible for an air burst, will be a more serious matter. The effects of the detonation of an atomic bomb at the surface of the ground or sea will be somewhere between those of an air burst and a subsurface explosion.

4.02. Information has been released concerning one underwater burst, namely, Test Baker at Bikini, and one near-surface burst above the ground, at Alamogordo, N.M. No underground atomic explosion has been reported and the results to be expected have been inferred from the observed effects of these explosions, from experiments made with TNT bombs, and from general considerations. It is because more is known about an atomic explosion under water than about the other types of subsurface or surface bursts, that the former will be described here in somewhat greater detail.

4.03. The phenomena accompanying an atomic underwater burst will depend on the depth and area of the body of water, on the distance below the surface at which the detonation occurs, and on the energy release of the bomb. In the Test Baker explosion at Bikini, a 20-kiloton TNT energy equivalent bomb was detonated at a depth greater than 50 feet below the surface of the lagoon, which was about 200 feet deep. The results of this test are described below. From them many of the effects to be expected from a deep underwater burst can be deduced.

Phenomena of Underwater Burst

4.04. As in the case of an air burst, a ball of fire, consisting of a huge bubble of extremely hot, highly compressed gases, is also formed in the underwater explosion of an atomic bomb. The rapid expansion of these gases produces a shock wave in the water similar to that accompanying an air burst. The shock wave, however, travels much faster in the water than it does in air.

4.05. If the depth of burst is not too great, as was presumably the case at Bikini, the ball of fire remains essentially intact until it comes to the surface. At this point the pressure in the giant bubble is released, and as a result of a complex series of events the water is thrown up, with great force, as a hollow, chimney-like, cylinder of spray. At the same time a shock or blast wave is sent out through the surrounding air.

4.06. The maximum height attained by the water column at Bikini, before it began to fall back due to the combined action of air resistance and gravity, was probably over 6,000 feet, the top being hidden by the atomic cloud. The column was about 2,000 feet across, the thickness of the walls being estimated at approximately 300 feet. Something like a million tons or more of water, largely in the form of spray, was carried upward in this manner. It included material which had been disturbed and sucked up from the bottom of the lagoon by the force of the explosion.

4.07. The contents of the gas bubble were vented through the top of the giant chimney of spray to form the atomic cloud seen in figure 1.24. This cloud resembled a cauliflower in shape, being roughly spherical with a diameter of some 6,000 feet. Its maximum height was 8,000 feet, which is considerably less than that reached by the atomic cloud in an air burst.

4.08. At 10 to 12 seconds after the underwater explosion at Bikini, the water falling back from the column on to the surface of the lagoon began to form the cloud of mist called the base surge (par. 1.25). This ring-shaped cloud, billowing upward, rapidly attained a height of over 900 feet, and was moving outward at an initial rate of more than a mile a minute. The outer radius of the cloud, growing rapidly at first and then more slowly, increased to nearly 3,000 yards, that is, 6,000 yards across, in 4 minutes, while its height increased to about 1,800

feet or about one-third mile. At this stage the base surge appeared to rise from the surface of the water and gradually merged with the other clouds in the sky, as described in paragraph 1.26. Intermittent rain from these clouds continued for about an hour after the explosion, but this rain probably contained little radioactivity after the first 10 minutes.

4.09. The disturbance created by the underwater burst at Bikini caused a series of waves to move outward from the center of the explosion across the surface of the lagoon. At 11 seconds after the explosion, the first wave had a maximum height of 94 feet and was about 340 yards from surface zero. This moved outward at high speed and was followed by a succession of waves of decreasing height (par. 4.23).

Chronological Development of the Underwater Burst

4.10. The development of the main phenomena associated with the underwater explosion at Bikini are represented diagrammatically in the series of drawings in figures 4.10a to e. The rise of the ball of fire occurs so rapidly that probably the first effect that can be seen by the eye is the rise of the water column, followed by the formation of the atomic cloud.

4.11. It should be noted that the initial nuclear radiations and the thermal radiation are almost completely absorbed in the water. Consequently, in this section, no more than passing mention will be made of these initial radiations.

Deep and Shallow Underwater Explosions

4.12. If an underwater burst took place at a very considerable depth under the surface, the gas bubble might well break up and lose its identity in a mass of turbulent water before reaching the surface. In this case there would be no column of water and spray, and consequently no base surge. Similarly, if an atomic bomb were exploded underwater in a harbor with a shallow bottom, there might be no true water column. However, in view of the uncertainties and the lack of precise knowledge concerning the requirements for the formation of the base surge, it is essential, from the defense standpoint, to be prepared for it. Throughout this manual, therefore, it will be assumed that an underwater burst will result in conditions such as were observed in Test Baker at Bikini.

Shock Wave in Water

4.13. Because of the difference in the physical nature of water as compared with air, the peak overpressures attained by the shock wave in water are much higher than in air. Further, the shock wave travels more rapidly in the water. The normal speed of sound in water is about a mile a second, and the initial speed of the shock wave is several times greater. On the other hand, the pressure falls off fairly rapidly with distance from the explosion.

4.14. The calculated values of the peak overpressures of the shock wave at various distances from the point of burst of a nominal (20-kiloton TNT energy equivalent) atomic bomb in deep water[1] are given in table 4.14. The overpressures are seen to be extremely high even at considerable distances from the explosion.

Table 4.14. Calculated Shock Wave Properties for Deep Underwater Explosion of Nominal Atomic Bomb

Distance from explosion (yards)	Peak overpressure (psi)	Impulse (psi-sec.)	Energy per unit area (ft. lb./sq. in.)
250	9,000	250	12,000
300	7,100	210	10,000
500	4,100	140	3,400
700	2,800	98	1,600
1,000	1,800	72	850
1,500	1,200	50	350
2,000	840	40	200

4.15. For the component plates of capital ships and also for small rigid underwater structures, the peak overpressure determines the degree of damage. But for large rigid structures, such as fixed subsurface construction, which are not permanently distorted by the shock front, the *impulse* of the shock wave becomes important at distances beyond the immediate range of destruction. The impulse takes into account both the pressure of the shock wave and the length of time it is applied. The variation of the impulse with distance from the explosion in deep water is indicated by the data in table 4.14. The units used are such that the pressure is in pounds per square inch and the time in seconds. Because of the cutoff, referred to below (par. 4.19), these values will be appreciably less near the surface of the water.

[1]Deep water is stipulated here because the effect of the shock wave reflected from the ocean bottom is not included.

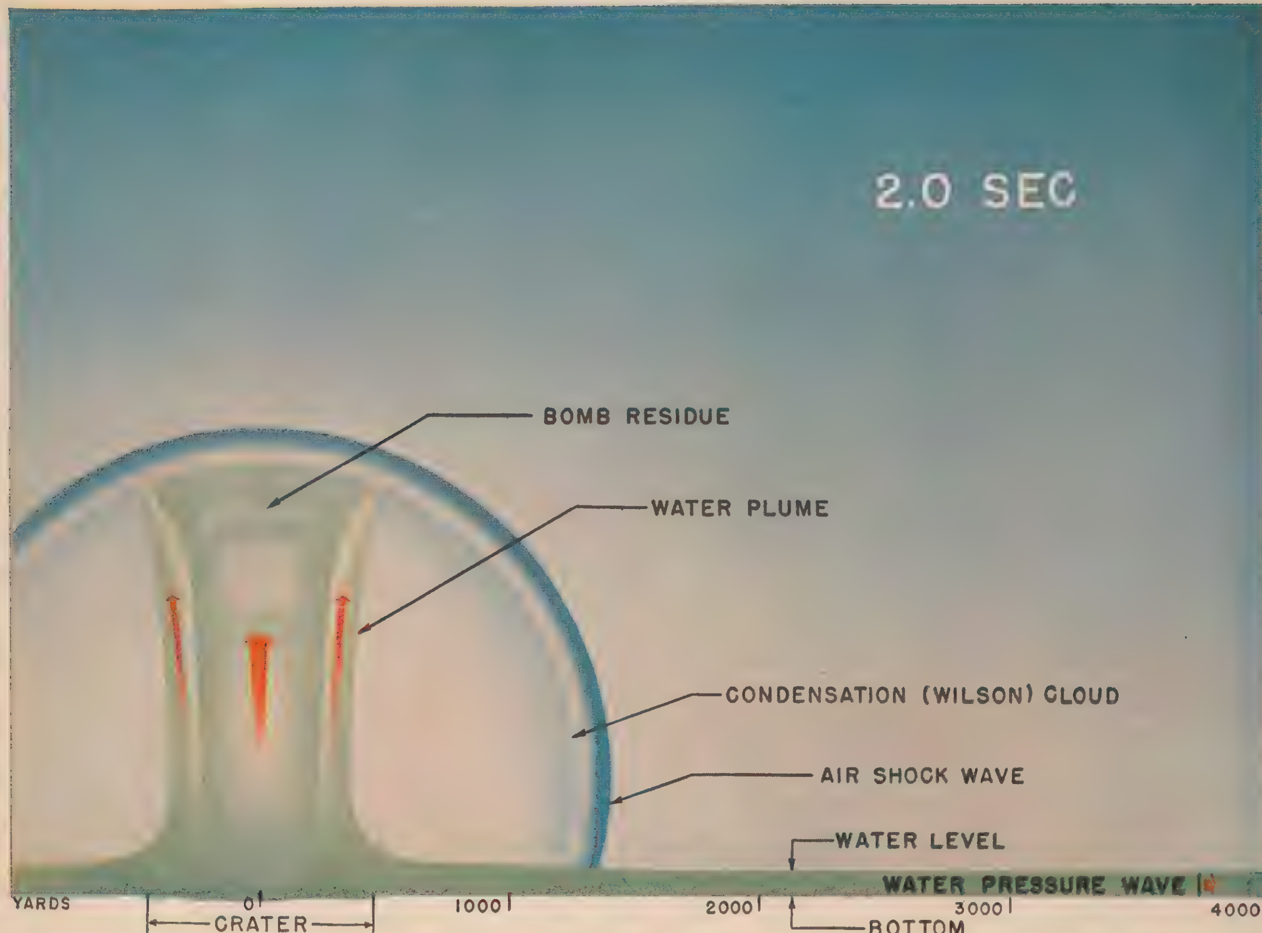


Figure 4.10a. Chronological development of a shallow underwater burst: 2.0 seconds after detonation.

When an atomic bomb is exploded under the surface of the water, essentially all of the instantaneous nuclear radiations and the thermal radiation are absorbed by the water. If the detonation occurs at a moderate depth, the bubble of hot gases will burst through the surface. As a result, a hollow chimney or "plume" of water and spray is shot upward, reaching a height of nearly 5,000 feet in 2 seconds. The gaseous bomb residue is then vented through the hollow central portion of the plume.

The explosion under water causes a shock wave to move outward, just as in the case of an air burst. The shock wave in water, however, travels more rapidly than in air, so that the front is more than 2 miles from surface zero at the end of 2 seconds. The expulsion of the hot gas bubble also produces a shock wave in the air as shown in the figure. The energy of the air blast is about one-fourth that due to the detonation of a nominal atomic bomb in the air.

After the air shock wave has passed, a dome-shaped cloud of condensed water droplets, called the Wilson cloud, is formed for a few seconds. While this phenomenon is of scientific interest, it has no significance as far as atomic attack or defense is concerned.

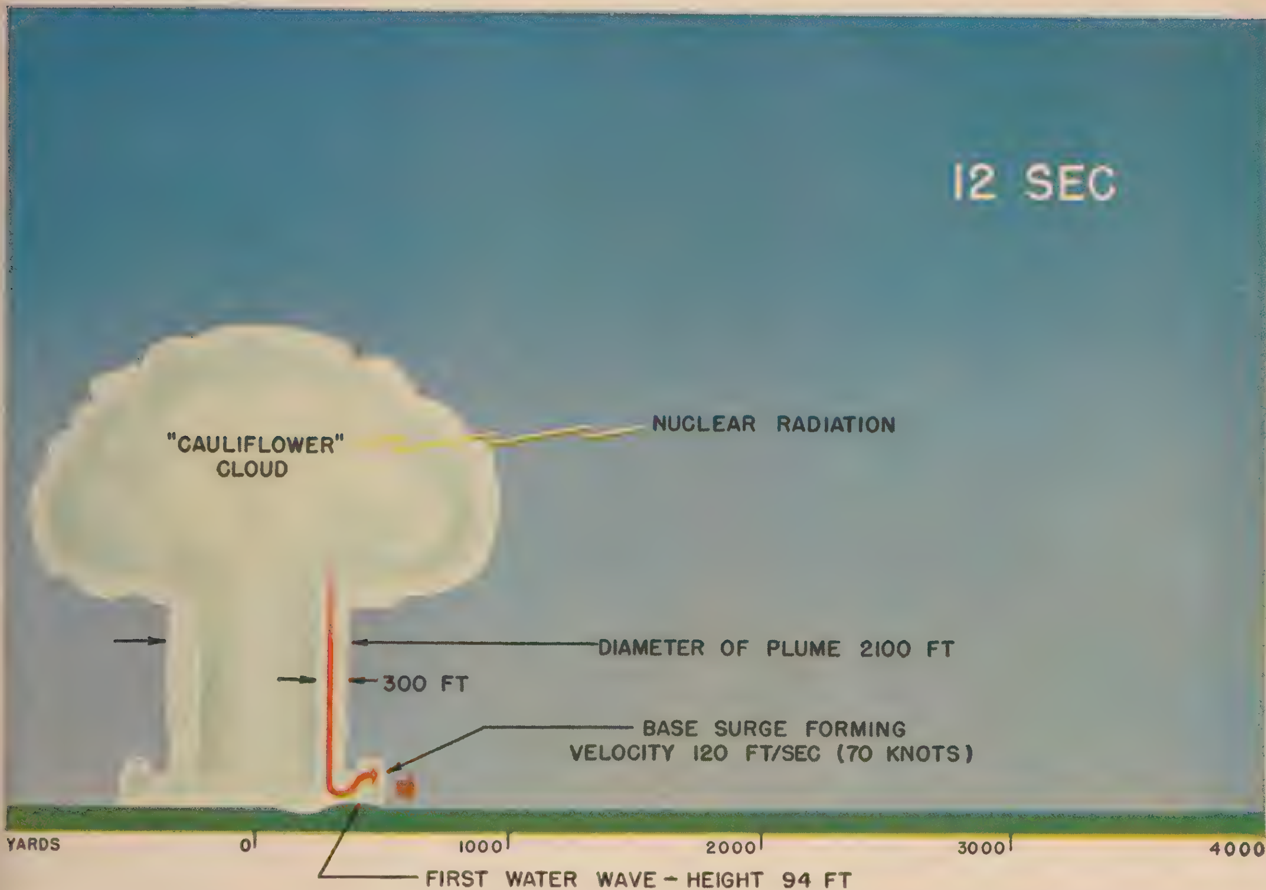


Figure 4.10b. Chronological development of a shallow underwater burst: 12 seconds after detonation.

At 12 seconds after the explosion, the diameter of the plume is about 2,100 feet, and its walls of water and spray are some 300 feet thick. The bomb residue venting through the central hollow portion spreads out to form the cauliflower-shaped atomic cloud, partly obscuring the top of the plume. The cloud is highly radioactive, due to the presence of fission products, and hence it emits nuclear radiations. But the distance from the surface is too great for these to be a significant hazard to personnel on ships surviving the explosion.

At 10 to 12 seconds after the underwater burst at Bikini, the water falling back from the plume reached the surface of the lagoon and produced around the base of the column a ring of highly radioactive mist, called the base surge. This ring-shaped cloud moved outward at the rate of about 120 feet per second (70 knots), parallel to the water surface.

The disturbance due to the underwater explosion caused large water waves to form. After 12 seconds, the first of these was 300 to 400 yards from surface zero, and its height, from crest to trough, was 94 feet.

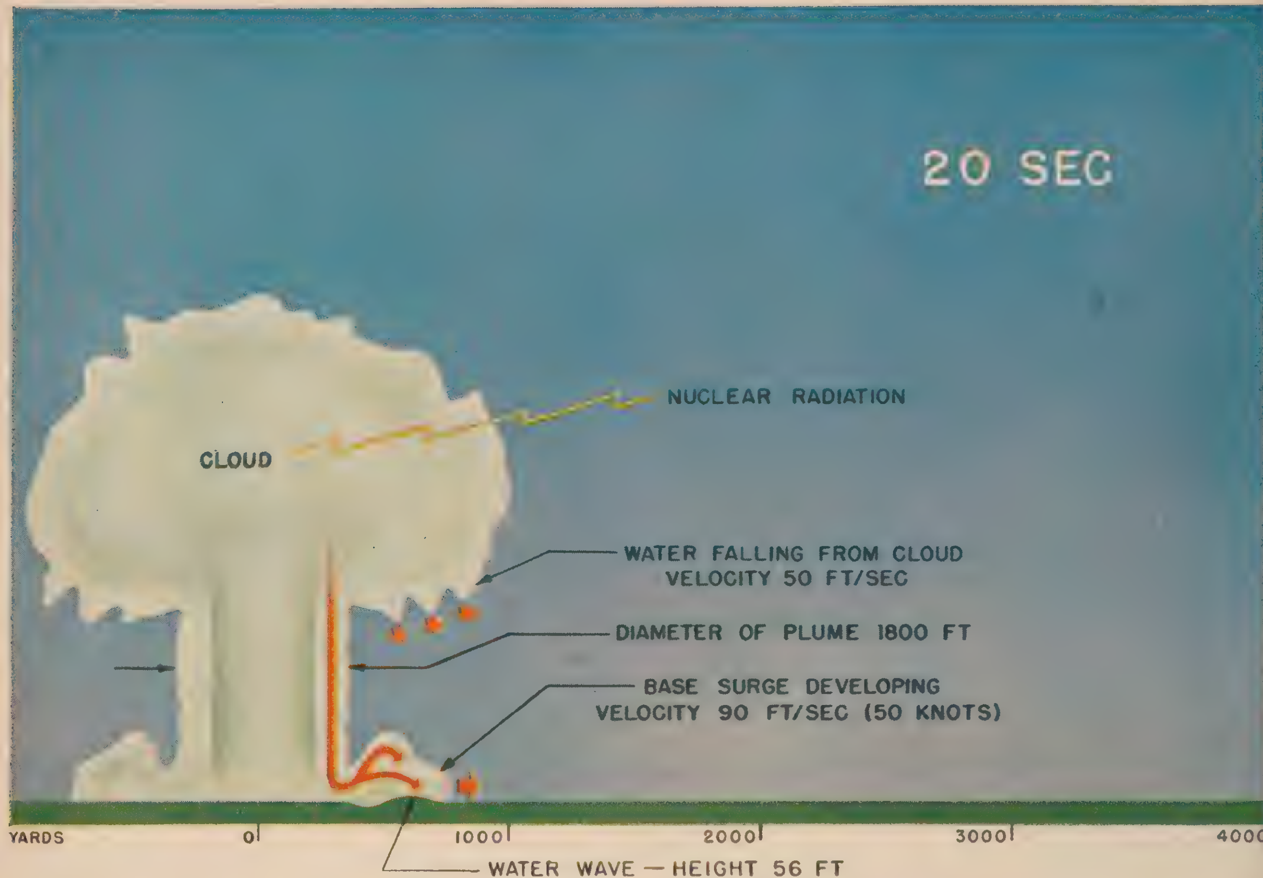


Figure 4.10c. Chronological development of a shallow underwater burst: 20 seconds after detonation.

As the water and spray forming the plume at Bikini continued to descend, the base surge cloud developed. The highly radioactive ring of mist billowed upward and moved outward across the surface of the water. At 20 seconds after the explosion the height of the base surge was about 800 feet, and the front was some 700 yards from surface zero. It was then progressing outward at the rapid rate of approximately 90 feet per second (50 knots).

At about this time large quantities of water and spray, sometimes called the massive water fall-out, began to descend from the cauliflower cloud. Its initial rate of fall was about 50 feet per second. Because of the loss of water from the plume, in one way and another, its diameter had now decreased to 1,800 feet.

By the end of 20 seconds, the first water wave had reached 500 to 600 yards from surface zero, and its height, from crest to trough, was roughly 56 feet.

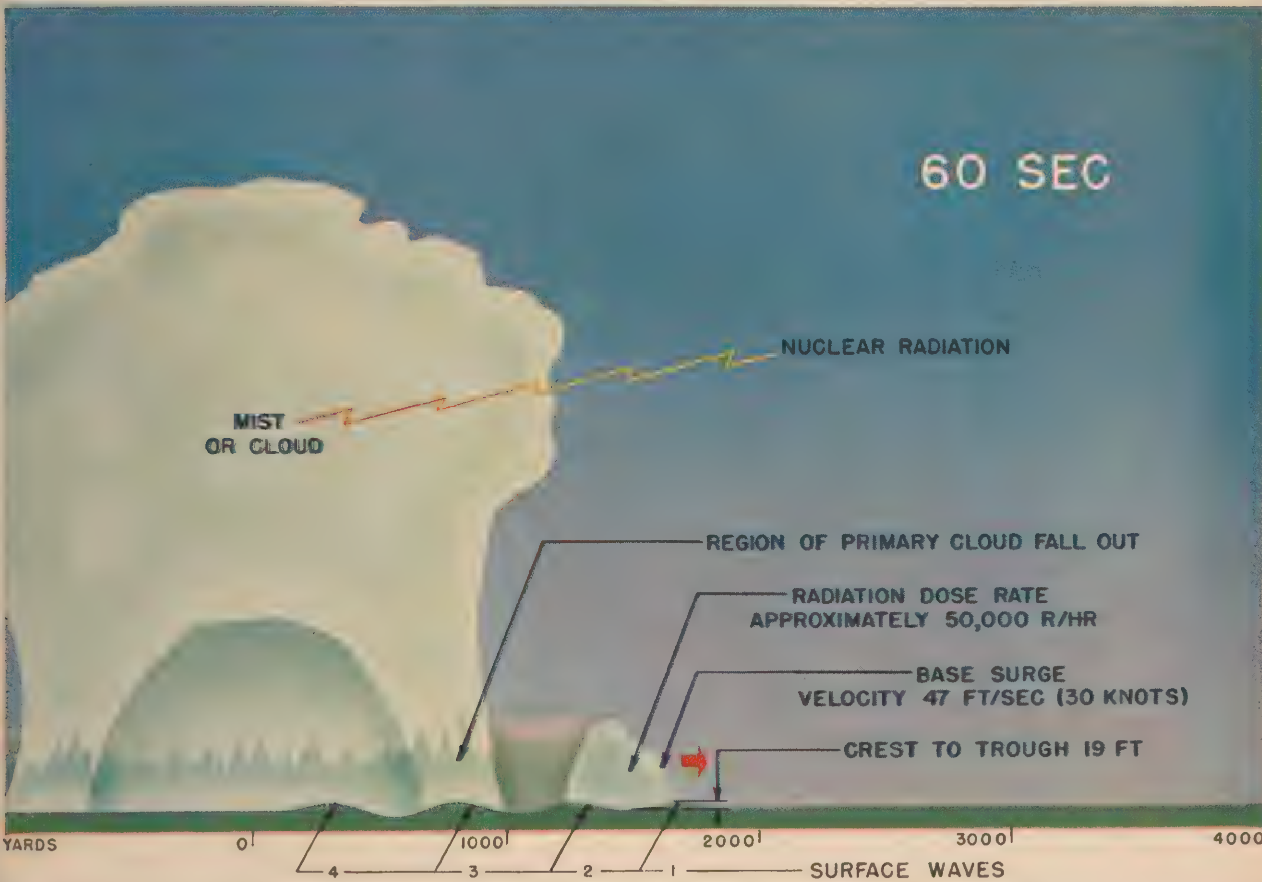


Figure 4.10d. Chronological development of a shallow underwater burst: 60 seconds after detonation.

At 60 seconds after the underwater burst at Bikini, the water falling from the cauliflower cloud just reached the surface of the lagoon, as indicated by the region of primary cloud fall-out in the figure. There was thus an essentially continuous ring of water and spray between the cloud and the surface.

At this time, the base surge cloud had become detached from the plume, so that its ring-like character was apparent, as shown in cross section in the figure. The height of the base surge was about 1,000 feet and its front, moving forward with a velocity of some 47 feet per second (30 knots), was approximately 1,600 yards from surface zero. Its intense radioactivity is indicated by the radiation dose rate of 50,000 roentgens per hour at 60 seconds after the detonation.

Several water waves have now developed, the first, with a height of 19 feet from crest to trough, being 1,600 to 1,700 yards from surface zero.

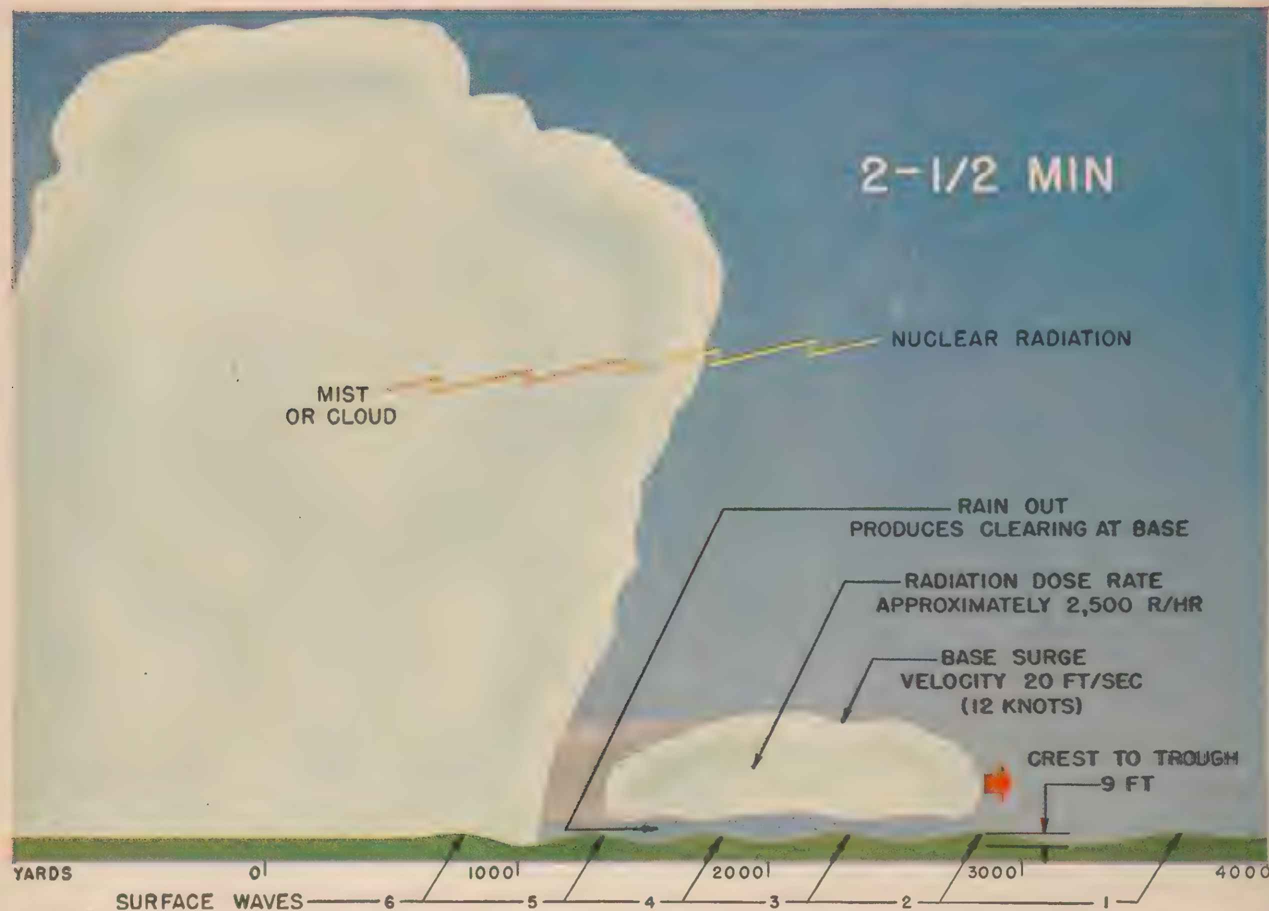


Figure 4.10e. Chronological development of a shallow underwater burst: $2\frac{1}{2}$ minutes after detonation.

By $2\frac{1}{2}$ minutes after the underwater explosion at Bikini, the front of the base surge was about 2,700 yards from surface zero and had almost attained its maximum thickness of roughly 1,800 feet. The greatest effective spread of the base surge, reached in roughly 4 minutes, was approximately 3,000 yards from surface zero, or nearly $3\frac{1}{2}$ miles across. Owing to natural decay of the fission products, to condensation of the water, and thinning out of the mist by air, the nuclear radiation dose rate at $2\frac{1}{2}$ minutes has decreased to 2,500 roentgens per hour. While this is much less than in figure 4.10d, it is still very considerable. At about this time, the base surge cloud appeared to be rising from the surface of the water. This effect was probably due to several factors, such as actual increase in altitude, thinning out of the cloud by engulfing air, and raining out of the larger drops of water.

The descent of water and spray from the plume and from condensation in the cauliflower cloud resulted in a continuous mass of mist or cloud down to the water surface. Ultimately, this merged with the base surge, which had spread and thinned out, and also with the natural clouds of the sky (fig. 1.26), to be finally dispersed by the wind.

4.16. For large structures in which the shock front causes a substantial amount of permanent deformation, the extent of damage depends essentially on the *energy* of the shock wave. The data for this property per unit area, expressed in foot-pounds per square inch, are also given in table 4.14. These will also be greatly reduced near the surface because of the cutoff. The values in table 4.14 are for the nominal 20-kiloton TNT energy equivalent bomb. For a bomb with an energy release equivalent to W kilotons of TNT, the distance would be multiplied roughly by $(W/20)^{1/3}$ for any given peak pressure, by $(W/20)^{2/3}$ for impulse, and by $(W/20)^{1/2}$ for the energy.

Reflected Shock Waves and Cutoff

4.17. The calculations from which the data in table 4.14 have been obtained were based on the supposition that there are no reflected shock waves. In water of moderate depth, such as that in Bikini lagoon, which is about 200 feet deep, the shock wave is reflected at the sea bottom, just as a shock wave in air is reflected at the surface of the ground or the water. In each case reflection occurs when the direct shock wave, moving in a given medium, e. g., air or water, meets a relatively rigid surface, e. g., firm ground. Similarly, there is reflection of the shock wave from the bottoms or hulls of ships, and from subsurface structures in general.

4.18. The reflected shock waves will, under certain conditions, fuse with the direct wave from the explosion, producing the Mach effect (par. 3.10). This will alter the values of the pressure, etc., given above. Actual observations at Bikini showed that the changes are not great, but the figures quoted cannot be used for shallow bursts or shallow targets because of surface effects which are explained in the following paragraph.

4.19. At the surface between the water and the air the shock wave moving in the water meets a much less rigid medium, the air. As a result, a reflected wave is sent back into the water, but this is a rarefaction or suction wave. When this reflected suction wave is combined with the direct wave it causes a sharp cut off of the pressure. This is shown in figure 4.19 which represents the variation of pressure with time after the explosion at a given point under water not too far from the surface. After the lapse of a short time, that is, the time required for the shock wave to travel from the explosion to the given point, the overpressure rises suddenly due to the arrival of the shock front. Then it decreases steadily as the shock pressure falls. In a short time the reflected suction wave arrives, and this causes the pressure to drop sharply, even below the initial pressure in the water.

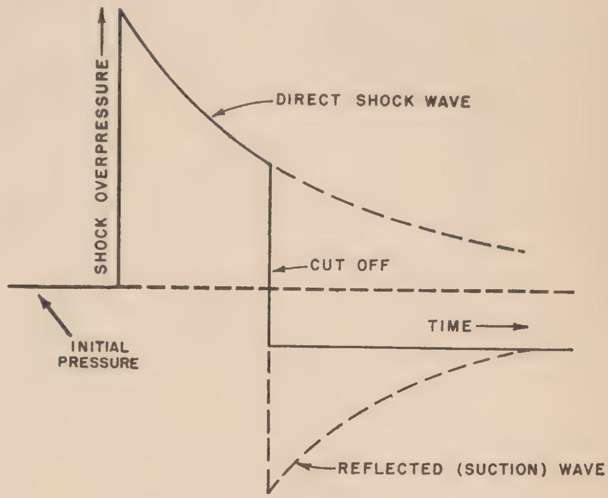


Figure 4.19. Diagrammatic representation of variation with time of shock overpressure in water, showing effect of cutoff due to reflection at surface.

4.20. By cutting off the pressure of the shock wave, the impulse and energy are correspondingly reduced, and as a result the amount of damage will be decreased. In the event of a moderately shallow explosion, the shock wave will strike the surface about the same time as, or sooner than, it strikes a submerged target near the surface, e. g., a ship bottom. In this case, the cutoff will occur very soon after the arrival of the shock front at the target, and the damage will be minimized. For a deep underwater burst, the effect of the cutoff will be less marked, especially for those targets that are some distance beneath the surface.

Air Blast from Underwater Burst

4.21 It was indicated above that in an underwater explosion, some of the energy of the explosion is transmitted as a shock wave in the air. From data obtained at Bikini it appeared that the variation of peak overpressures with distance for a shallow under-

water burst of a nominal atomic bomb is roughly equivalent to that obtained from the detonation of an 8-kiloton weapon. These pressures are considerable and could cause damage to the superstructures of ships and to nearby land installations.

4.22 The properties of the shock wave in air can be derived from the results given in chapter 3 by applying the scaling law in paragraph 3.31. The distances from surface zero, where the air shock may be regarded as originating, to any point on or above the surface of the water at which a specific overpressure will be experienced, can be obtained by multiplying the distances in figure 3.18 by $(8/20)^{1/3}$, that is, by about 3/4. If this is done, it is found that beyond 700 yards for a shallow underwater burst, the distance from surface zero at which a given overpressure will exist is about half the distance at which this same overpressure will be produced by a 2000-foot air burst of a nominal atomic bomb. For a deep underwater burst, the proportion of the energy going into the shock wave in air would be less, and the effective range of the air blast will be correspondingly smaller.

Water Wave Formation

4.23. The formation of water waves in Test Baker at Bikini was referred to in paragraph 4.09. In an aerial photograph taken 5 minutes after the detonation, the entire area discernible through the clouds is seen to be covered by concentric waves. The estimated maximum wave heights, for distances from 350 yards to 4,000 yards from the explosion, are given in table 4.23; the height, in feet, is measured from the crest to the following trough. The times of arrival of the crests at the various distances are also given. From these figures it can be calculated that the waves were moving outward with a speed of about 1 mile per minute, but this decreased somewhat at farther distances from the bomb. It is evident that waves of such considerable height and velocity are capable of causing damage.

Table 4.23. Estimated Maximum Wave Heights in Test Baker

Distance from explosion (yards)	350	700	1,000	1,500	2,000	3,000	4,000
Maximum height of wave (feet)	94	45	36	22	16	12	9
Arrival time (seconds)	11	24	35	55	74	114	154

4.24. The wave heights given in table 4.23 refer to the highest, generally the first, wave to reach the various points. This wave was followed by others of lesser height, at intervals of 20 seconds or more. The waves began breaking on the shore at Bikini, approximately 6,200 yards from the explosion center, 5 minutes after the burst, and continued to arrive for about 15 minutes. The maximum wave height at the beach was 7 feet.

Instantaneous Nuclear Radiation in Underwater Burst

4.25. In an air burst it is possible to distinguish easily between the immediate nuclear radiation and the residual radioactivity, if any, because the gamma rays, neutrons, and beta particles from the ball of fire and the atomic cloud are out of range of the earth in about a minute (par. 3.48). But in the case of a subsurface burst it is not possible to make such a sharp distinction. However, one thing can be stated definitely—the instantaneous gamma rays and neutrons accompanying the actual fission process (par. 2.19) are of no significance in an underwater burst. Passage through a few yards of water attenuates these radiations to such an extent that they can be disregarded completely.

Radioactivity of the Base Surge

4.26. Were it not for the fact that the base surge is highly radioactive, due to the presence of most of the fission products in the water of the column, it would represent merely a curious phenomenon. However, on account of its radioactivity, the base surge may represent a serious hazard. The exact conditions required for its formation are not known with certainty, but as indicated earlier (par. 4.12), it will be assumed here that all underwater atomic explosions, at moderate depths, will be accompanied by a base surge.

4.27. The radiation dosage received from the base surge arises in two ways. As the radioactive cloud passes over an area, the latter is exposed to radiation for the short time while the cloud is in transit. This gives what may be called the *transit dose.* In addition, some of the contaminated water droplets will fall as rain from the base surge, leading to the deposition of radioactive material on surfaces. The resulting radiation dosage may be referred to as the

deposit dose or *contamination dose*. The transit dose thus somewhat resembles the immediate radiation, while the deposit dose is due to residual radioactivity.

4.28. From observations made at Bikini it appeared that the transit dose due to the base surge was roughly equal to the deposit dose, but this distribution of the radioactivity might well vary with the conditions of the underwater burst. It should be remembered, however, that whereas exposure to the transit dose occurs only during a few minutes while the base surge is passing by, the deposited drops of water carry with them contamination which continues to emit beta and gamma radiations for a considerable time.

4.29. An indication of the magnitude of the transit dosage received from the base surge, at various distances from surface zero, can be obtained from figure 4.29. The radiation dosages, which are expressed as usual in roentgens (par. 3.51), are based on those actually recorded at Test Baker at Bikini. If there had been no wind, the various lines would have been true circles, but a surface wind of about 5 knots caused the transit dosages to be greater downwind than at corresponding points upwind.

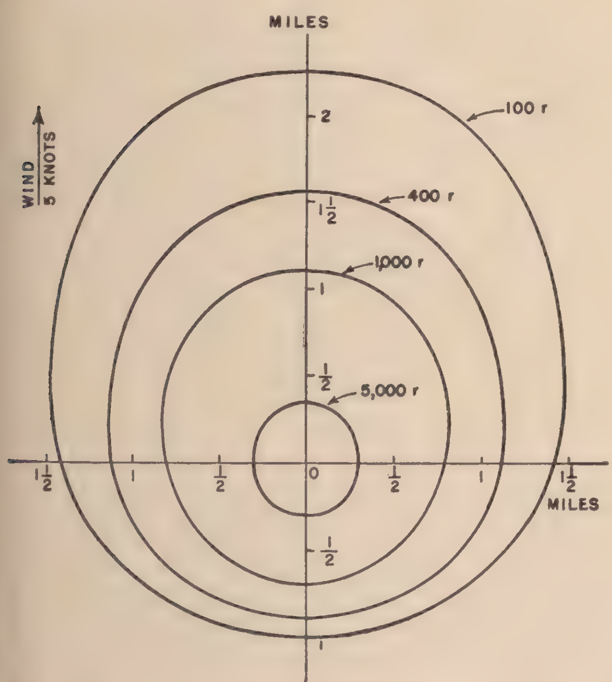


Figure 4.29. Transit doses of radiation received from base surge at various distances from surface zero due to an underwater atomic explosion; based on measurements at Test Baker with a 5-knot surface wind.

4.30. It is seen that a person remaining exposed on the deck of a ship about 2,500 yards downwind from surface zero, would receive 450 roentgens, that is the LD/50 (par. 3.52), merely due to the transit of the base surge. However, as it would take about 3 minutes for the cloud of mist to reach the point, it might be feasible for the ship, which would be essentially undamaged, to take evasive action.

4.31. In general, the radioactive mist of the base surge is most hazardous within a few minutes of its formation. The activity decreases rapidly in a short time for three reasons. First, the mixing of large quantities of air with the base surge as it spreads out results in a dilution or thinning out of the active material. Second, increase of size of the water droplets causes some of them to fall as rain, thus removing part of the radioactivity from the cloud of mist. And third, the suspended fission products rapidly lose their activity due to natural decay (par. 2.25). Calculations indicate that the dose rate within the base surge at Bikini decreased by a factor of about 400 in the interval between 1 and 4 minutes after the burst. Further, due to the apparent lifting or thinning of the cloud from the surface of the water, which occurred toward the end of this period, the transit dose on a ship was then relatively small.

4.32. For protective purposes, an important point to remember about the base surge is that it expands and travels laterally with the wind, parallel to the surface of the water. Its nature is such that it engulfs everything over which it moves. The transit dose of radiation could thus not be avoided merely by taking cover in a shelter, any part of which is open. On board ship, adequate protection from the base surge would be obtained only below decks with the hatches and doors closed, and the ventilation system temporarily shut down. Fortunately, such extreme measures would be necessary only for a few minutes.

4.33. Radioactive rain may continue to fall from the base surge cloud for some time. Shelter from the rain, to prevent clothing becoming contaminated, can then be the only precaution to be taken immediately. Later, of course, the contamination would have to be removed from the ship.

Residual Radioactivity—The Fall-Out

4.34. In addition to the effect of the base surge, radioactive contamination will result from the particles carried down by the fall-out of masses of water from the column and the cauliflower cloud (fig. 4.10c). Partly because of the great weight of the water thrown into the air by the explosion, and partly because of the lower temperature, the cloud does not ascend to such heights as in an air burst. Hence, the fall-out begins very soon after the explosion, and at Bikini it was quite appreciable within a minute. A considerable proportion of the radioactive fission products were thus deposited in a short time inside a radius of a few thousand yards from surface zero (fig. 4.10e).

4.35. Since it is impossible to distinguish between deposited contamination from the fall-out and that from the base surge, the radiation dosages received from these two sources are taken together. The estimated total dosages in roentgens for various distances from surface zero are shown in the diagram in figure 4.35. The data were obtained at Bikini with a 5-knot surface wind blowing. It should be noted that the dosages given represent the total number of roentgens which would be received from the contamination over an extended period of time, although actually more than half of this total is reached within 30 minutes. It is particularly desirable, therefore, to avoid the contamination in the early stages.

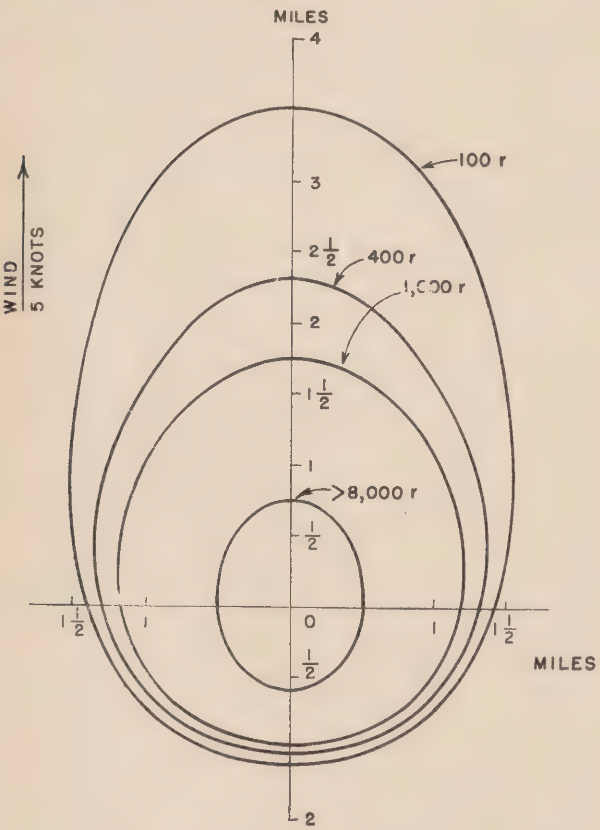


Figure 4.35. Total radiation dosages from base surge and fall-out at various distances from surface zero due to an underwater atomic explosion; based on measurements at Test Baker with a 5-knot surface wind.

Radioactive Contamination of the Water

4.36. In an underwater burst, most of the radioactive fission products, and the residual uranium or plutonium which has not undergone fission, will eventually fall back into the water. Since these substances will be spread through a large body of water, the hazard from radioactivity will not be serious, except near the center of the explosion soon after the burst. As a result of continual mixing with uncontaminated water, from around and below, and because of natural decay, the radiation dosage decreases fairly quickly.

4.37. At Bikini it was estimated that 4 hours after Test Baker a maximum radiation dosage rate of about 3 roentgens per hour extended over an area of 16.6 square miles of the lagoon, with an average diameter of 4.6 miles. Although a ship could not remain in the contaminated area for any length of time soon after the explosion, passage across the water would not be a hazard to the crew. For example, a vessel steaming at 20 knots would take about 12 minutes to cross the contaminated area 4 hours after the explosion. During this time the radiation dosage from the water would be less than three-fourths of a roentgen.

4.38. At Bikini part of the rapid loss in activity of the water was due to the fission products settling to the bottom of the lagoon. Most of this occurred within the first week after Test Baker. The fission products were then distributed over an area of some 60 square miles. Later tests showed that there was no tendency for the activity to spread.

4.39. Because of the large amount of sodium present in the water, in the form of salt, it might be thought that the neutrons released in an underwater atomic explosion would produce radioactive sodium

which would add to the contamination of the water (par. 3.64). Actually, most of the neutrons will be taken up by the hydrogen in the water to form a nonradioactive product (heavy water). Some radioactive sodium will no doubt be formed, but the quantity will be small in comparison with the fission products. In any event, since its half life is less than 15 hours, it will lose its activity fairly rapidly.

Radioactive Contamination of Land Areas

4.40. The underwater burst at Bikini took place far enough from shore to prevent any appreciable contamination of land areas. Radioactive rain fell on some islands, at a distance from the explosion, but its activity was not great. It is possible, however, that if there were an underwater explosion in a harbor, for example, significant amounts of the base surge and the fall-out would contaminate dock facilities, warehouses, etc.

4.41. A rough estimate has been made of the radiation dose rate that might be expected on adjacent land areas after an underwater explosion of a nominal atomic bomb. The results based on measurements made in connection with Test Baker at Bikini, where a 5-knot wind was blowing, are shown in figure 4.41. The lines indicate the distances from surface zero at which the dosage rates are 400, 50 and 10 roentgens per hour at 1 hour after the explosion. Thus, at a point 2 miles downwind, the dosage rate at this time will be about 50 roentgens per hour. Because of the rapid decrease in the activity, especially in the initial stages, as described in par. 2.27, this will have declined to 5 roentgens per hour 6 hours later, and to about 1 roentgen per hour after a day.

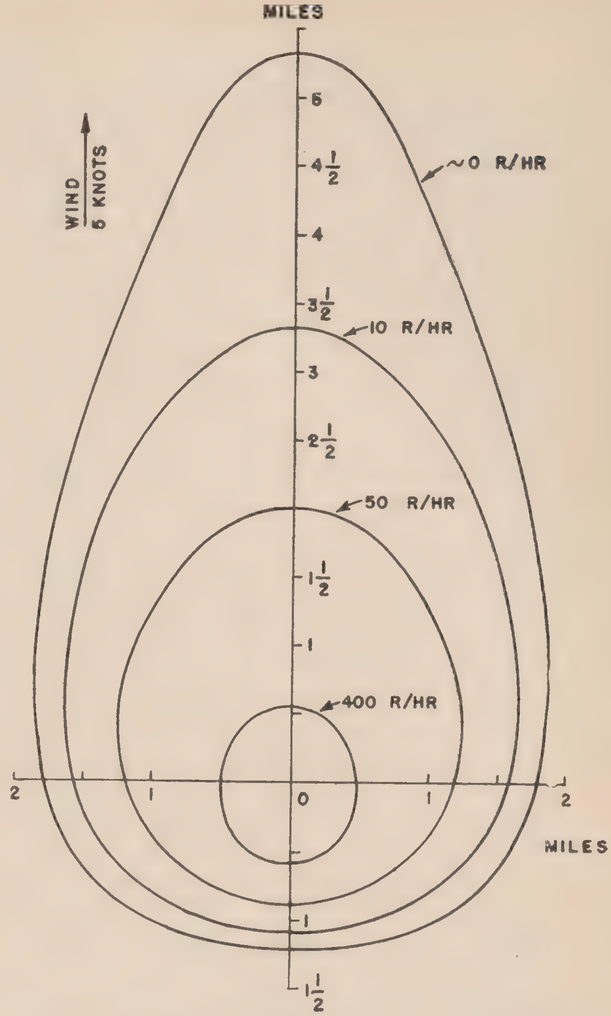


Figure 4.41. Estimated radiation intensities at various distances from surface zero at 1 hour after Test Baker.

Long Term Residual Radioactivity

4.42. After the lapse of several weeks when the gamma activity due to fission products is no longer a very serious external hazard, another aspect of the residual radioactivity becomes relatively more important. This is the internal hazard from inhalation or ingestion of long life fission products, or plutonium which may have escaped fission when the bomb exploded. The fission products emit beta particles and plutonium emits alpha particles. The potential hazard differs from that due to gamma radiation in the respect that it is an internal hazard, that is to say, it arises only if the fission products or plutonium actually enter the body. Plutonium is essentially harmless outside the body in the small quantities likely to be encountered after an atomic explosion. Fission products, on the other hand, can be both internal and external hazards.

4.43. As long as the gamma and beta activity due to fission products is at all appreciable, there is no need to be concerned about plutonium. Any measures which reduce the hazard from the former will automatically take care of the latter. When the activity due to fission products is no longer important, months or years after the explosion, it may in some cases still be necessary to take precautions against alpha particle emitters. Laboratory analyses can

determine the extent of this hazard. The half life of the plutonium used in the atomic bomb is about 24,000 years. The decay is consequently so slow that the amount present at any one place does not change appreciably in several years. Plutonium is therefore to be regarded as a long term hazard.

4.44. Uranium, the other fissionable material which has been used in atomic bombs, is definitely not an external hazard, and would be an internal hazard only if very large amounts entered the body. The chances of this occurring after an atomic explosion are so remote as to make them not worth considering.

CHARACTERISTICS OF AN UNDERGROUND BURST

Crater and Column

4.45. If an atomic bomb were exploded under the ground, a ball of fire, consisting of a huge bubble of extremely hot, highly compressed gases, would undoubtedly form. The expansion of the gases would impart an outward and upward movement to the surrounding earth. If the explosion occurred at not too great a depth, probably down to 600 feet, the gas bubble would break through to the surface of the earth. At the same time large quantities of earth, rock and other debris would be thrown upward with great force, leaving a crater in the ground.

4.46. It has been estimated that if a nominal (20-kiloton TNT energy equivalent) atomic bomb were dropped from the air and penetrated underground in sandy soil to a depth of 50 feet before exploding, it would produce a crater about 350 feet deep and 400 yards in diameter. This would mean that a rough, uneven, column, somewhat analogous to that resulting from an underwater burst, containing over a million tons of dirt, contaminated with radioactive material, would be hurled from the earth's surface.

4.47. The shape and size of the area over which the expelled material would be spread is governed to a great extent by the strength and direction of the wind. Tests made with 2,500-pound TNT charges, with a wind velocity of 15 to 20 miles per hour, indicate distribution of crater material as far as 1 mile downwind and 0.2 mile upwind, from the explosion center. It is believed that for a nominal atomic bomb these distances would be increased by a factor of four or more, depending on the wind velocity. However, much of the debris will fall back into and in the vicinity of the crater.

Base Surge

4.48. When the material from the column falls back to earth, it will probably produce an expanding cloud of fine dust particles, similar to the base surge observed at Bikini (fig. 4.48). This will move outward from the center of the explosion and perhaps be carried downwind. Eventually the particles will settle out and produce radioactive contamination over a large area, the extent of which will depend on the depth of the explosion, the nature of the soil, and the atmospheric conditions. It is believed that a sandy terrain will be particularly conducive to base surge formation in an underground burst.

Fall-Out

4.49. The atomic cloud formed in the case of an underground burst will contain a very large amount of dirt and other debris in the form of fragments of various sizes raised by the violence of the explosion. As a result there will be a considerable fall-out. The larger pieces will be the first to reach the earth and so they will be deposited near the center of the explosion. But the smaller particles will remain in the air for some time and may be carried great distances by the wind before they eventually settle out.

4.50. Particles with diameters of a thousandth of an inch or less, will take days to reach the earth. During this time they may be carried by the wind some distance from the point of the explosion. Particles which require a day, for example, to fall to the ground may travel 100 miles or more downwind. The radioactive particles will thus fall over a very large area, and the contamination will not be as serious as might appear at first sight, except within a mile or so of the crater. This matter will be considered more fully below (par. 4.60).

Shock Wave in the Ground

4.51. The rapid expansion of the hot bubble of compressed gas formed in the underground burst of an atomic bomb is accompanied by a shock wave in the earth. Its effect is somewhat similar to that of an earthquake of moderate intensity, except that the disturbance originates near the surface instead of at great depths. Among other things, this difference in depth means that the pressures in the earth

Figure 4.48. Underground explosion of 160 tons of TNT conducted at Dugway Proving Ground, Utah, in May of 1951. The base surge can be clearly seen during the early stages of formation. The similarity of the appearance of this explosion with the underwater atomic explosion shown in fig. 1.25 should be noted.

shock waves caused by the atomic bomb fall off more rapidly with distance than do those due to earthquake waves.

4.52. The peak pressure of the shock wave is largely dependent on the depth of the burst. For a relatively shallow burst the pressure is reduced by the surface of the earth giving way. The greater the depth of the explosion, the later will come the relief of pressure at the surface, and the smaller the decrease in the shock pressure.

4.53. The extent to which this relief of pressure is delayed is related to the distribution of the energy between earth shock and other effects. It has been estimated that at the practical depths of penetration into the ground of a heavy bomb, say about 50 feet, about 25 percent of the energy will appear in the ground shock wave. The remaining 75 percent will be spent in producing air blast, fusing and vaporizing the soil, forming a column and crater, and nuclear radiations.[2] A greater penetration before detonation would, of course, result in a larger proportion of the energy being used to cause earth shock.

4.54. In addition to the depth of the burst below the earth's surface the strength of the ground shock wave, from the standpoint of the damage produced, will be largely dependent on the character of the soil. Certain soils, such as heavy wet clays, are good transmitters of ground shock, while light, silty loams are very poor in this respect with sandy clay coming between these extremes.

4.55. For the reason just indicated, the range for a particular degree of ground shock damage may vary by a ratio of 3 to 1 in different soils for the same yield of underground explosion. For example, the same damage which would occur at a distance of 1 mile from an explosion in a light loam could be expected to extend out to a radius of 3 miles in a heavy wet clay.

4.56. The presence of rock strata at not more than 200 to 300 feet below the surface would cause the shock wave to be reflected to some extent. As in the case of air and underground bursts, this would intensify the effect of the shock. In some cases, the rock can also act as an elastic medium through which some of the energy of the shock wave is fed back into the soil above, thus increasing its motion.

[2]It should be noted that essentially all of the thermal radiation from the bomb will be absorbed by the ground.

Air Blast from Underground Burst

4.57. As in an underwater burst, part of the energy released by the bomb in an underground explosion appears as a shock (or blast) wave in the air. As stated previously, it is believed that, in the case of a burst 50 feet underground about 75 percent of the energy will not contribute to the ground shock. If we assume that the fraction of this energy imparted to the air as blast is the same as that similarly imparted in the moderately shallow underwater burst, the variation of peak overpressures with distance from ground zero will be the same as for the underwater burst, that is, roughly equivalent to that resulting from the detonation of an 8-kiloton weapon in free air (par. 4.21).

4.58. While the foregoing estimate is to be regarded as being in the nature of a guess, it can be used to give a rough indication of the effects of the air blast accompanying an underground explosion. As explained in paragraph 4.22, the distance from ground zero at which a particular peak pressure is observed will thus be about half that for an air burst of a nominal atomic bomb.

Instantaneous Nuclear Radiation in Underground Burst

4.59. The characteristics of the instantaneous nuclear radiation after an underground atomic explosion will be similar to those for an underwater burst. The gamma rays and neutrons emitted at the instant of fission are absorbed in a few yards of earth, and so they are of no significance. Induced activity caused by the neutrons when they are absorbed may, however, not be negligible. This will constitute part of the residual radioactivity.

Residual Radioactivity in the Crater

4.60. While the residual radioactivity in an underground burst will resemble, to some extent, that from an underwater burst, there will be some important differences. For one thing, since the density of soil is greater than that of water, the volume

of contaminated material thrown into the air will be smaller in the underground explosion. Because much of this will consist of fairly large pieces of soil, dirt and rock, it will fall directly back into the crater, and not be carried away to descend at a distance from the explosion. The area that will be highly contaminated with radioactive fission products, etc., may thus be less than in the case of an underwater burst.

4.61. Although the area covered may be less, the radiation intensity will be correspondingly greater in places fairly close to the underground burst. In addition to the higher initial concentration of radioactive material near ground zero, the activity will fall off less rapidly with time than for an underwater burst. It will be recalled that after Test Baker the radiation dosage in Bikini lagoon decreased very quickly, because of mixing with the surrounding water. In an underground burst such mixing, and consequent dilution, will not take place. The decrease in activity of the crater will thus depend on natural radioactive decay.

4.62. The contamination of the ground near the explosion will be enhanced by induced radioactivity caused by neutrons released at the time of the explosion. Although sodium is present only to a small extent in soil, it appears that appreciable amounts of radioactive sodium could be formed in an underground burst. However, as this substance has a half life of less than 15 hours its contribution to the total activity will disappear almost completely in the course of a few days. Since it will not be possible to approach the crater during this period, in any case, the induced activity in and around the crater can be ignored.

4.63. It has been estimated that at 1 hour after the explosion the radiation dose rate within one-half mile of surface zero will be about 2,000 roentgens per hour. Radiation intensities of this magnitude would make the explosion area uninhabitable for some time.

Radioactivity of Base Surge and Fall-Out

4.64. As stated in paragraph 4.48, it is probable that a base surge of contaminated dust particles will form as the result of an underground explosion. If so, there will be a transit dose of radiation as the base surge passes by. In addition, a deposit dose will be left on the ground. The relative and actual amounts of these doses will depend on various conditions, such as the depth of burst and the nature of the soil. A fairly shallow burst in soft or sandy soil, for example, will probably be associated with a considerable base surge of high activity.

4.65. While most of the column of soil, etc., thrown into the air by the subsurface burst will fall back into the crater, the smaller particles will be carried up as a cloud and will ultimately descend in the fall-out. It is expected that this will cover a much larger area than for an underwater burst. The reason is that many contaminated dust particles will remain in the air for an appreciable time, and will fall some distance away. Water droplets either grow in size and fall fairly soon, or they are vaporized and dispersed. Dust particles, on the other hand, do not change size to any extent. Since particles of various sizes will be formed in the explosion, they will cover, and contaminate, a considerable area. The larger particles will fall near the point of burst, and the smaller ones at increasing distances.

4.66. The situation as far as radioactive contamination is concerned is, however, not as bad as might be expected. This is because of the rapid decay of the fission product activity, especially in the early stages. The longer a contaminated particle remains suspended before falling, the smaller will be its activity when it reaches the ground. Particles which fall some distance from the burst will have been in the air for a relatively long time. Consequently, at greater distances from the explosion, the activity of the particles will be less. It is to be expected, therefore, that after an underground explosion radioactive contamination will be a serious hazard only in and near the crater region, as long as precautions are taken to prevent entry of contaminated dust into the body by inhalation and ingestion.

4.67. Since there has been no reported underground burst of an atomic bomb from which to obtain the necessary data, it is not possible to give any indication of the area of serious contamination to be expected. A rough idea may perhaps be obtained from the calculations which will be referred to below in the section on surface bursts. But, much will depend on the depth of the burst, the nature of the terrain, the

height to which the cloud ascends, and the strength and direction of the winds at various altitudes. Actual tracking of the cloud may prove to be the only practical solution to the problem.

4.68. If the underground atomic explosion should be followed, or accompanied, by high winds, due to natural causes, large amounts of contaminated dirt may be carried away, as in a dust storm. If, for some reason, much of this should fall in one area, perhaps carried down by rain, a serious radiation hazard might be created. The possibility of such unusual occurrences must be kept in mind.

The Long Term Residual Radioactivity

4.69. The long term residual radioactivity due to long-lived fission products or plutonium will probably be more significant after an underground burst than after an underwater explosion. In the latter case, most of the residual plutonium will fall into the water, where it will gradually spread out and eventually settle to the bottom. In an underground burst, however, a considerable proportion will descend near the center of the explosion and remain there. The radioactive material will be in the form of dust particles which may be easily ingested or inhaled. Although fission products, unless removed, will still represent the main hazard for the first few months or so, attention may subsequently have to be paid to contamination by plutonium. The general considerations here are similar to those described in the section on underwater burst.

CHARACTERISTICS OF A SURFACE BURST

General Description

4.70. A surface burst is regarded as one taking place within 50 feet of the surface of the ground or water. Although the phenomena will, in general, be intermediate between those of an air burst and of a subsurface burst, the actual effects will differ in degree, but not in kind, according to the height of burst. The description given here will be based largely on the observations made in the test explosion at Alamogordo, N.M.

4.71. In a surface burst, the ball of fire, in its rapid initial growth and before it begins to ascend, will touch the surface of the ground (fig. 4.71). Due to the intense heat a considerable amount of rock, soil and other material located in the area will be vaporized and taken into the ball of fire. As the latter rises and cools, these substances will separate out as small particles contaminated with fission products and other radioactive residues of the bomb.

4.72. The vaporization of the earth, etc., and the pressure of the shock wave will result in the formation of a crater. The size of the crater will depend on the height of the burst and the character of the soil. It is believed that there will not be appreciable crater formation unless the nominal atomic bomb is exploded at an altitude of less than 100 feet.

4.73. As the ball of fire rises, large amounts of dirt particles will be sucked up, especially if the burst has taken place at a low level. Ultimately, some of these will form the column and may produce the mushroom cloud, just as in an air burst (ch. 3). The main difference in the case of a surface burst is that the column and cloud are much more heavily loaded with dust and dirt. At Alamogordo the cloud column rose to an altitude of about 40,000 feet before spreading out, and this may be taken as more or less typical of surface bursts in general.

4.74. If an atomic bomb is exploded at or near the surface of water, large amounts of the latter will be vaporized and carried up into the atomic cloud. The effects will be essentially the same as in an air burst over water, as observed in Test Able at Bikini, except that a much greater quantity of water will be carried up with the ball of fire. At high altitudes this will ultimately condense to form drops contaminated with the radioactive residues of the bomb.

Air Blast and Ground Shock

4.75. The over-all blast effect due to the air shock from a surface burst will be less than that from an air burst. For one thing, part of the energy of the bomb is used up in vaporizing materials on the surface and in forming a crater. In addition, up to 15 percent of the energy may go into ground shock. The main point, however, is that because the bomb explodes close to the earth's surface, the overpressure near ground zero will be much greater than for an air burst, but it will fall off more rapidly with increasing distance from ground zero.

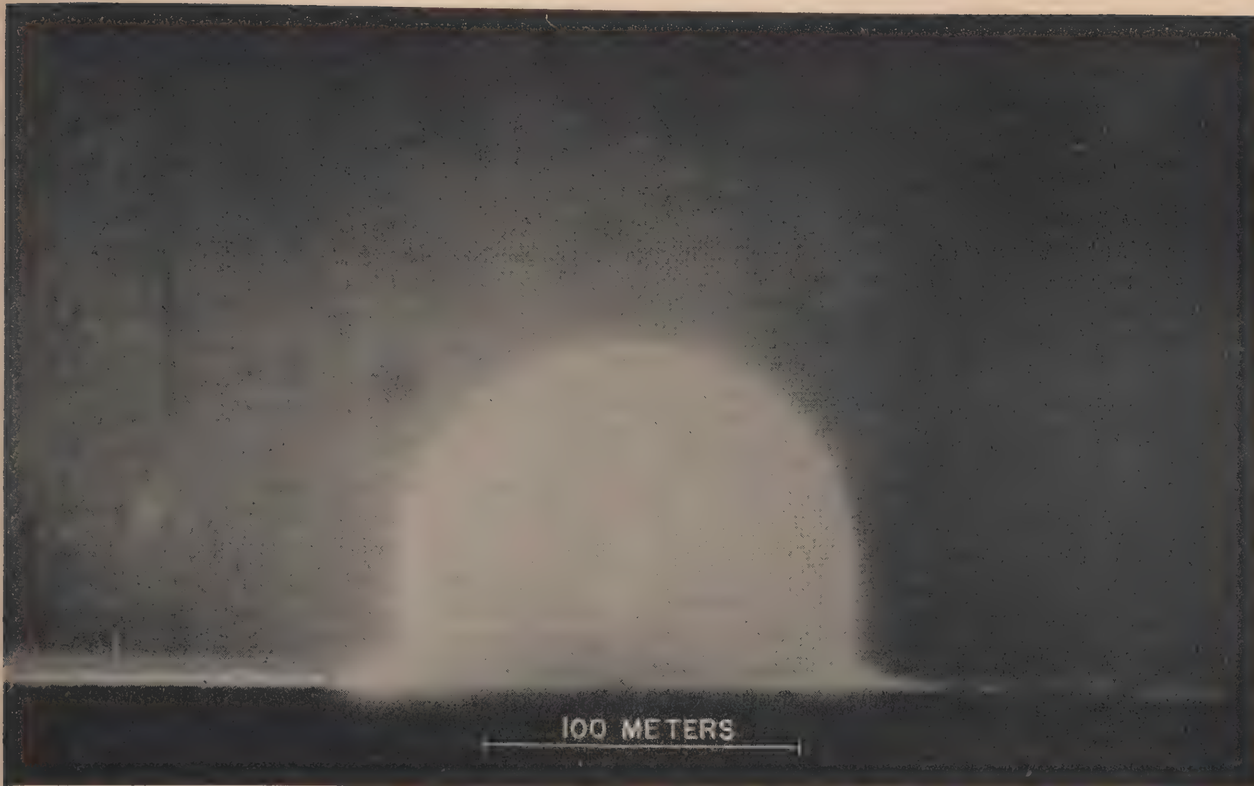


Figure 4.71. An early stage of the atomic test at Alamogordo, N. M., showing the extensive contact between the fire ball and the ground. The bomb was detonated at the top of a 100 foot tower. A later stage of this same burst is shown in figure 3.16.

4.76. As a result, energy will be wasted on targets close to ground zero which could have been destroyed by much lower overpressures. At the same time, the overpressures at some distance away will be too low to cause any considerable damage. In other words, there will be an "overdestruction" of nearby targets, and an "underdestruction" of those further away. The energy that has gone to produce ground shock may contribute, however, to the destruction of underground targets protected from the air blast.

Thermal (Heat) Radiation

4.77. The general characteristics of the thermal radiation in an atomic explosion at the surface will be essentially the same as for an air burst, described in chapter 3. The radiation will be emitted from the ball of fire in two pulses, the second, in the interval between about one-hundredth of a second and 3 seconds after the explosion, being the main cause of injury to personnel. As stated earlier (par. 3.39), if evasive action can be taken within a second or so, part of the heat radiation may be avoided.

4.78. Since thermal radiation travels in straight lines, the intensity at any point is determined by the slant range or actual distance from the explosion. In this respect, there may be some advantage to be gained from a surface burst, as seen from figure 4.78.

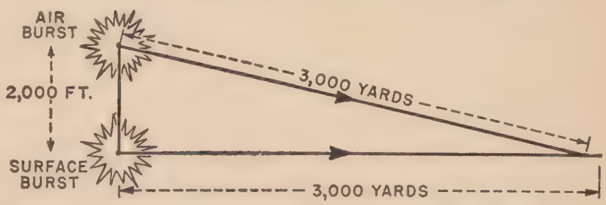


Figure 4.78. Comparison of ranges of thermal radiation in an air burst and a surface burst.

But the gain is not as much as might at first appear. On a fairly clear day, a nominal atomic bomb would deliver 3 calories per square centimeter of heat energy, sufficient to cause moderate skin burns, out

to about 3,000 yards from the point of burst. If the bomb were detonated at a height of 2,000 feet, the distance from ground zero would be a little over 2,900 yards, as compared with 3,000 yards if the explosion took place exactly on the surface.[3]

4.79. It is seen from the foregoing that the range for moderate skin burns may be increased by about 100 yards, as a result of exploding the bomb on the ground instead of at an altitude of 2,000 feet. The increased range for slight burns is even less. In any case, the calculations do not take into account the possibility of obstructions at or near ground level. In a region where there are buildings of any kind, the resulting cut off of thermal radiation from a low level explosion would far outweigh the effect of the increased range.

4.80. Only for a surface explosion on open terrain or at sea might the effects of thermal radiation be greater than for a burst at an appreciable altitude. But even this is not certain, for trenches and foxholes would provide much better shelter in the event of a surface or low air burst than in the case of a high air burst (fig. 4.80).

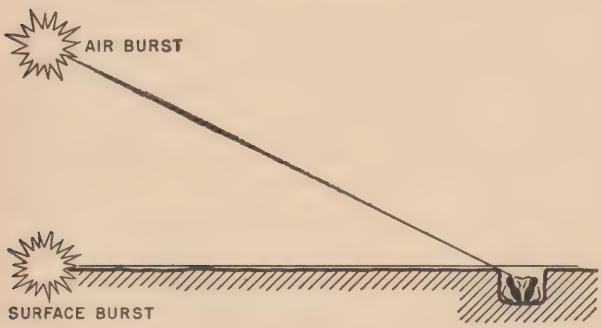


Figure 4.80. Trenches and foxholes provide better shelter from thermal radiation in the case of a surface burst than from a high air burst.

Immediate Nuclear Radiation

4.81. The immediate nuclear radiation from a surface burst will be similar to that in an air burst. However, it may extend for a slightly longer period, because the ball of fire and the radioactive cloud would have to travel a greater distance before the gamma rays and neutrons were out of effective range of the earth's surface (par. 3.48). The total dosage of immediate nuclear radiations received at a given distance from the explosion might thus be somewhat greater than from an air burst.

4.82. As with thermal radiation, considered above, the intensity of the immediate nuclear radiation at any point on the ground depends mainly on the actual distance from the point of burst. Consequently, the range at which the LD/50 of nuclear radiation, i.e., 450 roentgens, is received will be greater for a surface explosion than for an air burst. Thus, the LD/50 range from ground zero should be 1,420 yards, as compared with 1,250 yards if the burst took place at an altitude of 2,000 feet.

4.83. If the low-level, atomic explosion occurred in a more or less built-up area, the structures through which it passed would serve to reduce, even though they did not completely block, the gamma radiation. Similarly, as indicated above, trenches and foxholes would offer more effective protection than in the case of an air burst. It is doubtful, therefore, whether the over-all hazard due to the immediate nuclear radiation from a surface burst would be greater than from an air burst. For practical purposes, therefore, it would be advisable to treat these two types of burst as the same, as far as initial nuclear radiation is concerned.

Residual Radioactivity

4.84. With respect to residual radioactivity, an atomic explosion at a low level would produce effects somewhat similar to a subsurface burst. A considerable amount of dirt and other debris, or water, would be hurled into the air, and upon descending it might produce a base surge. There will also be an appreciable fall-out from the atomic cloud, although it will not be as great as for a subsurface burst. Crater formation, due to a detonation near or at ground level, will tend to increase the base surge and fall-out.

Contamination of Crater Material

4.85. If a crater is formed, it will be highly contaminated, partly from the condensation on the ground of the fission products, etc., from the ball of fire, partly from the fall-out of heavier pieces, and partly from radioactivity induced by neutrons. The approximate radiation dose rates, in roentgens

[3]The calculations are based on the assumption that during the first 3 seconds the ball of fire rises by about the same amount in each case.

per hour, measured on the ground at Alamogordo, 1 hour after the detonation, are given in table 4.85, for various distances from ground zero. As already mentioned, the height of burst was about 100 feet in this case.

Table 4.85. Radiation Dose Rates on Ground at 1 Hour after Explosion

Distance from ground zero (yards)	Dose rate (roentgens per hour)
0	8,000
100	5,000
200	600
300	150
400	30
750	5
1,250	0.07

4.86. It can be seen from these figures that within and near the crater the radiation dose rate is high enough to make the region uninhabitable soon after the explosion. Nevertheless, an hour after the explosion, a vehicle traveling at 30 miles per hour or more could probably cross the widest part without serious hazard to its occupants. It would probably be 6 hours or more before it would be safe to walk across the area. But to stay for any length of time would, of course, be out of the question for a few days.

The Fall-Out

4.87. The extent of the fall-out from a surface explosion would lie between those for an air burst and a subsurface burst. In the former case it will generally present no hazard, and the main effects in the latter case will usually be observed not too far from the point of detonation. To judge from the experience at Alamogordo, the residual radiation due to the fall-out from a surface explosion will be relatively small, except near the crater. The reason for this, as indicated earlier, is that the dust particles are carried up to a height of 40,000 feet or more, and by the time they descend the activity of the contaminating fission products has greatly decreased.

4.88. The general opinion is that the fall-out following a low air burst might be an inconvenience, but it would not usually represent an operational hazard. While continuous occupation of the crater region might have to be suspended for a few days, it would be possible to work in the area for short periods within an hour or so of the explosion. At appreciable distances from the point of burst the danger from radioactive contamination would usually be small. However, special circumstances, such as rain at the time of, or soon after, the explosion, or abnormal air currents, might cause an exceptional amount of radioactive material to fall at a particular place. Tracking of the atomic cloud for some hours after the explosion might thus be advisable.

COMPARISON OF CONTAMINATING AND NON-CONTAMINATING BURSTS

4.89. In reviewing the nuclear radiation (or radiological) aspects of atomic explosions, it is seen that while an air burst, as described in chapter 3 is noncontaminating, subsurface and surface bursts are contaminating in character. An explosion in the air, at an altitude of more than 500 feet, will not leave sufficient radioactive residue on the ground, to interfere with military operations but the other types of burst contaminate the surroundings with radioactivity which persists for some time after the explosion.

4.90. Due mainly to the formation of a base surge, and partly to the water fall-out, appreciable contamination will be spread over ships and over adjacent land areas in the case of an underwater burst. The water in the region of the explosion will, however, be passable without appreciable hazard in a ship, within a few hours.

4.91. An underground explosion will leave a highly contaminated crater, in which it will not be possible to operate for some time. A base surge of dust particles may spread the contamination over a large area. In general, however, the activity will fall off rapidly with increasing distance from the explosion. In the case of a surface burst, the nearby ground will be somewhat contaminated, but it will be possible to cross the area soon after the explosion. Residual radioactivity at a distance will usually be negligible.

4.92. While an air burst is noncontaminating, it still offers a radiological hazard because of the immediate gamma radiation emitted within a minute of the explosion. This radiation is also significant in a

surface burst. In subsurface explosions the immediate gamma rays are absorbed by the water or the ground, and so they are no hazard. The base surge will, however, be a source of radiation during its actual transit across an area, apart from the contamination left after it has passed. The transit dose from the base surge is thus, in a sense, a form of immediate nuclear radiation, since it is received within a short time, although its origin is different from the immediate nuclear radiation in the case of an air burst.

A near-surface atomic explosion during the 1951 tests at Eniwetok.

SUMMARY

In the underwater explosion of an atomic bomb a huge, hollow column of water and spray is thrown up. The gases from the ball of fire are vented through the column and form the cauliflower-shaped cloud at the top. As the water from the column falls back to the surface, the base surge is produced. The explosion is accompanied by the transmission of a strong shock wave through the water. Some of the energy of the bomb also appears as air blast.

The thermal and instantaneous nuclear radiations are absorbed in the water, and so have a negligible effect in an underwater burst. But the radioactivity carried by the base surge is important. The radiation dosage received consists of two parts —the transit dose, during the short time the base surge cloud is in transit, and the deposit (or contamination) dose due to the deposition of radioactive matter. Additional radioactive contamination arises from the fall-out from the column and cloud.

An underground burst will result in the formation of a large crater. The earth and rocks hurled upward may weigh over a million tons and a base surge of radioactive dust particles will form when the dirt, etc., falls to the ground. There will be a strong ground-shock wave, similar to an earthquake of moderate intensity, and some of the energy of the bomb will also be propagated as air blast.

The thermal and instantaneous nuclear radiations are absorbed by the soil, but the base surge will contribute a transit dose and a deposit dose of radiation, as in an underwater burst. Because of the large amount of dust raised, a considerable fall-out is expected.

The characteristics of a surface burst will lie between those of an air burst and a subsurface burst. Energy will go into both air blast and ground shock. The thermal and immediate nuclear radiations will be similar to those in an air burst. The base surge and fall-out will be less than for a subsurface burst.

Chapter 5

RADIOLOGICAL WARFARE

RW AGENTS AND THEIR EFFECTS

Purpose of Radiological Warfare

5.01. The military value of the atomic bomb lies largely in its use as a blast weapon. But, as seen in the preceding chapter, it may under certain conditions cause radioactive contamination which will make it hazardous to occupy a ship or an area. While this may be regarded as a secondary application of the atomic bomb, there is a possibility that radioactive material, apart from the bomb, may be used directly for military purposes, with the object of contaminating persons, structures, equipment, or areas. This is referred to as *radiological warfare*, abbreviated to RW, and the contaminating material is called the RW agent.

5.02. The purpose of RW would be to induce personnel to evacuate an important area such as a city, an industrial region, a military establishment, or an airport without actually destroying it, by creating a condition which would result in casualties or be a source of potential casualties unless the area were temporarily evacuated. However, in the course of time the activity would decay, and occupation would be possible with little or no rehabilitation. RW could also be used to contaminate a strategically important industrial plant which has been damaged by other weapons, thus delaying reconstruction and repair of the plant. Its use in an enemy's combat and communication zone might be effective in hampering and disrupting his logistical activities.

Characteristics of RW Agents

5.03. As seen in chapter 2, there are three kinds of radiations emitted by radioactive materials, namely —alpha particles, beta particles, and gamma rays. Alpha particles cannot travel more than an inch or two in air, they are unable to penetrate the outer layers of the skin, and they are stopped by ordinary clothing. Hence, a radioactive substance emitting alpha particles is a hazard only if it actually enters the body. Although beta particles have a range of a few feet in air, they are unable to pass through moderately thick clothing. Beta particle emitters are consequently not dangerous outside the body, unless they are actually on the skin.

5.04. Because of the necessity of getting into the body, or on the skin, before they can do any damage, substances emitting only alpha or beta particles are of little value as RW agents. Gamma rays, however, being similar to X-rays, can travel considerable distances in air, are not stopped by clothing, and can easily penetrate the skin. Radioactive materials emitting gamma rays thus offer possibilities for use as RW agents. Mere removal from the skin or the clothing, or the use of gas masks and gloves, will not provide sufficient protection in an area contaminated with emitters of gamma rays. Only by keeping the contamination at a distance or by the use of suitable heavy shielding is protection possible.

5.05. In general, substances which give off gamma rays also emit either alpha particles or beta particles, the latter type being the more common. Since the gamma rays are highly penetrating, and can act over a considerable distance, they represent the only hazard outside the body. But if the radioactive substance gets into the body, especially by breathing, the injury caused by the alpha or beta particles is added to that due to the gamma radiation.

5.06. The essential requirements of an RW agent are, first, that it should be a gamma-ray emitter. Second, the energy of the radiation must be fairly high, for the higher the energy the greater the distance it will penetrate through the air. And third, the half life of the radioactive substance must be neither too short nor too long, say, between about 2 weeks and 6 months. If the half life of the RW agent is very short, its decay will be so rapid that it will have to be made immediately before use, and hence stockpiling to any extent will not be feasible. On the other hand, substances with long half lives have relatively weak activity, and will have to be used in larger amounts to be effective. Furthermore, these substances may deny subsequent reoccupation of the area.

Production of RW Agents

5.07. Apart from the atomic bomb, which can be an indirect RW weapon, RW agents may be produced in two ways. Both, however, involve the use of a nuclear reactor, sometimes called an atomic "pile." In the reactor certain uranium nuclei un-

dergo slow or controlled fission by neutrons. It is the same process as occurs in the atomic bomb made with uranium, except that it takes place in a controlled, rather than in an uncontrolled, manner. There is, consequently, no explosion, the energy being liberated gradually instead of suddenly. As a result of the fission reaction, the same (or similar) radioactive products are formed in a reactor as in the explosion of a bomb. They are, however, not dispersed, but remain in the reactor.

5.08. Of the neutrons liberated in the fission process, some are taken up by the fissionable uranium nuclei, which then suffer fission in turn, while others are absorbed or captured by a nonfissionable form (isotope) of uranium. As a result, the latter is changed into a third, unstable form of uranium. In the course of a few days, following upon two stages of radioactive decay, this turns into the new element, plutonium. During the operation of a nuclear reactor, therefore, fission products and plutonium slowly accumulate. From the mixture, containing much unchanged uranium, the plutonium is extracted. This is how plutonium is produced for use in atomic bombs.

5.09. For every pound of plutonium made in a nuclear reactor, there will be formed an approximately equal weight of highly radioactive fission products. The complex mixture so obtained, as a byproduct, could be used directly as an RW agent. Its chief disadvantage is that it consists of many substances of various half lives, and while the initial activity falls off rapidly, some activity will linger for years.

5.10. This disadvantage might be overcome by extracting a particular radioactive substance, having desirable RW properties, from the mixture. But the extraction process will be difficult and costly. In any event, the substance chosen may constitute a small fraction only of the total fission products. The mixture is so complex that no single species represents more than about 3 percent of the total.

5.11. Another method of using a nuclear reactor to produce RW agents is to expose certain nonradioactive elements to the action of neutrons. By a process exactly similar to that described in paragraph 3.60, the neutrons are captured by, and induce radioactivity in, these elements. By a proper choice of materials, it is thus possible to prepare RW agents with the required characteristics.

5.12. The advantage of being able to make a particular material in this way is offset by the disadvantage that the neutrons used in the reactor to produce the RW agent are not available for the production of plutonium for use in atomic bombs. There is thus the question of choosing between the military value of RW and of the atomic bomb. In certain circumstances, such as those indicated earlier, the former might prove more effective than the latter.

STOCKPILING AND DELIVERY OF RW AGENTS

Decay of RW Agents

5.13. There are two important respects in which RW agents differ from other weapons, including the atomic bomb. First, all other weapons can be made in advance, in preparation for an emergency. They can be kept for a long time without undergoing serious deterioration. This is not true for RW agents. Stockpiling is virtually impossible, for natural decay will result in a continuous loss of active material. A substance with a half life of a month will have its activity reduced to one-half at the end of a month, to one-quarter at the end of 2 months, and to one-eighth at the end of 3 months. The production of RW agents is a slow process, at best, and the continual and unavoidable loss represents a serious drawback.

Dangers of Handling and Delivery

5.14. The second difference between RW agents and other weapons is that by taking suitable precautions the latter can be handled comparatively safely. An RW agent, on the other hand, is continually giving off the harmful radiations. Since the agent, to be effective, will be one emitting gamma rays of considerable penetrating power, personnel handling it must always be protected by thick and heavy shielding of lead or other metal.

5.15. The necessity for shielding complicates delivery of the RW agent by airplane. Theoretically, the weapon should be very compact, because a few pounds of a suitable agent would be sufficient to contaminate a square mile of territory. However, the weight of the shielding necessary to protect the crew

of the airplane would to a great extent nullify the advantage of compactness of the weapon.

5.16. Another aspect of the delivery problem is the heat liberated by the RW agent. A fair proportion of the energy of the particles and rays emitted by the radioactive material will be converted into heat in the container. The latter will thus become very hot. Some provision will have to be made for removal of this heat while the weapon is being stored and delivered.

DEFENSIVE CHARACTERISTICS OF RW

Favorable Characteristics

5.17. From the standpoint of defense against RW attack, there are some characteristics of the weapon which may be regarded as favorable while others are unfavorable. Among the former, there is the fact that RW agents can be readily detected by the same instruments as would be used to measure radiation intensities due to contamination after an atomic explosion (see chapter 8). From a knowledge of the dosage rate, a commanding officer will be able to determine how long his men may remain in the area with reasonable safety. The same considerations would apply to a ship subjected to RW attack.

5.18. Another favorable defensive aspect of RW is the improbability that any considerable area or ship will be so highly contaminated as to make it necessary to vacate it at once. In any event, very few, if any, personnel will be incapacitated immediately by radiation. An important position could then be held for a time, by taking the inevitable risk of war, until arrangements could be made for a series of replacements. No individual would then need to remain in the danger area long enough to obtain a serious dose of radiation.

5.19. Operations could thus be continued in a contaminated position if the occupying force was either willing to accept the risk of possible future losses, or if there were periodic replacement of personnel to avoid overexposure of any individual. On the other hand, if the position were not of sufficient importance, it could be evacuated by the defenders without suffering casualties. If the decision was made to remain in an area which had been subjected to an RW attack, the radiation intensity could be greatly reduced by digging new foxholes and using the fresh earth as a shield. Clearing part of the ground with a bulldozer, if practical, would also help in this connection.

5.20. In a built-up area the RW agent will fall mainly on the ground and on the roofs of buildings. Provided the radioactive material can be prevented from entering the body, some protection from the radiations could thus be obtained in the interiors of buildings. The extent of protection would depend on the thickness of the walls and on the distance of the individual from the contamination.

5.21. Another point to remember is that all radioactive substances undergo spontaneous decay at a definite rate. Consequently, the radiation dosage rate will decrease steadily with time, unless the region is subject to further RW attack. Of course, if the RW agent has a fairly long half life, the decrease in the dosage rate may not be appreciable for several weeks or months. In contrast, the decay of the radioactivity following a bomb explosion will be very rapid during the first few hours or days after the detonation.

Unfavorable Characteristics

5.22. The chief unfavorable defensive characteristic of RW is the psychological aspect. Because the radiations cannot be detected by the senses, and their effects are generally delayed, RW agents may be used to create confusion or panic. Proper indoctrination of personnel and the general availability of detecting instruments should do much to overcome this possibility and prevent unnecessary evacuation of lightly contaminated areas.

5.23. Another unfavorable aspect of RW, from the point of view of the defense, is that unlike chemical and bacteriological warfare it does not require direct contact between the individual and the radioactive agent in order to produce biological effects, since the gamma rays have considerable range in air. This makes avoidance of contaminated areas and individual protection much more difficult.

SUMMARY

Radiological warfare (or RW) is the use of radioactive materials, called RW agents, to contaminate persons, objects or areas. The main purpose of RW would be to render such areas temporarily uninhabitable, without destroying buildings and equipment. An effective RW agent should be a substance with a half life from 2 weeks to 6 months, and it should emit gamma rays of fairly high energy.

RW agents can be produced in nuclear reactors in two ways. First, in the form of a complex mixture of fission products obtained at the same time as plutonium is made for use in atomic bombs. Particular substances might be extracted from the mixture, but the process is expensive and difficult. Second, certain elements can be made radioactive by exposure to neutrons in a nuclear reactor. This procedure would, however, reduce the capacity of the reactor for the production of plutonium.

RW agents differ from all other types of weapons because they cannot be stockpiled. Further, they cannot be handled safely without extensive precautions, and can be approached only if there is sufficient shielding.

RW agents are readily detected by proper instruments, and appropriate defensive action can be taken. The effects of the radiations are not immediate, and an important position could be held after an RW attack, either by accepting the risk of possible future losses, or by periodic replacement of troops. The main unfavorable aspect of RW from the defense standpoint is the psychological effect associated with its use.

Chapter 6

EFFECTS OF ATOMIC EXPLOSIONS ON STRUCTURES AND MATÉRIEL

INTRODUCTION

Causes of Damage

6.01. The damage to structures and matériel that results from an atomic explosion is due to two main causes; (1) blast and shock,[1] (2) heat and fire. Neither the immediate nuclear radiation nor the residual radioactivity produce any mechanical destruction, although radiation from the contamination may make it hazardous for personnel to remain in a building or to operate equipment for some time. In general, structures and matériel will be rendered useless by the combined action of two or more of these factors. But since they produce damage in different ways they will be considered separately.

6.02. In addition to the main causes of damage referred to above there are certain minor causes which require brief mention. In a subsurface explosion large amounts of water or dirt and other debris will be hurled upward and will subsequently descend on ships or buildings, etc. Such masses of water or debris are capable of causing much damage. However, in the range within which this is likely to be significant, the destruction due to shock and blast will be virtually complete. The massive fall-out will thus merely overdestroy the target, and so it can be ignored from the defense standpoint.

6.03. Another possible source of damage in the underwater burst is wave formation. As seen in table 4.23, the water waves produced by an atomic explosion can be of considerable height. Depending on the location and relative heading of a ship, these waves can sweep over topside, inundating or even capsizing the vessel. In any case, the ship is likely to pitch, roll or swing violently. Apart from the fact that the successive waves at any point are of steadily decreasing height, the water waves produced in an atomic explosion are like those of natural origin, and the effects will be similar.

Effects—Land, Sea and Air

6.04. In describing the effects of atomic explosions of various types on structures and matériel, it will be convenient to consider separately the results on land, at sea, and in the air. Thus, all structures on land, irrespective of the Service by which they are used, will be treated in the land section. However, the discussion of aircraft presents a difficult problem in making an exact classification. Parked aircraft on a carrier will be referred to in the sea section, but parked aircraft on land will be considered in that dealing with the effects on aircraft. Aircraft in flight will, of course, be treated in the latter section. Rations are referred to under the effects on land, although special consideration is given to potable water at sea.

[1]Both blast and shock result from the shock wave accompanying the explosion. The term "blast" generally is used for the effect in air, because it is like (and is accompanied by) a very strong wind. In water or under ground, however, it is referred to as "shock," because the effect is more like a sudden impact.

BLAST AND SHOCK EFFECTS

Air Blast—General Considerations

6.05. The general nature of the effect on a structure of a shock or blast wave in air is that of a giant blow, due to the sudden onset of pressure, followed by a more or less steady force. This continues until the pressure wave reaches the rear of the structure, when it exerts a crushing or squeezing effect. Because of the action of these forces, a properly anchored weak structure may be crushed without being displaced bodily. On the other hand, a strong structure may move without being crushed.

6.06. The ability of a building to withstand blast depends primarily on its strength and, to a lesser degree, on its shape and on the number of openings which can serve to relieve the pressure on the outside walls. The strength is determined mainly by the type of construction, but this can be modified by various structural details which are not obvious to the eye. The strongest buildings are heavily-framed steel and reinforced concrete structures, while the weakest are probably certain shed-type industrial buildings (shops) having light frames and long spans of unsupported beams.

6.07. The effect of shape is not very marked since most buildings are rectangular in form. A long, narrow structure will be more resistant to blast striking it on the narrow end than on the side. However, if struck on the side, such a building would probably suffer more than one having similar dimensions in both directions.

6.08. The shape effect is more evident in certain auxiliary parts of structures, such as smoke stacks and chords of bridges. Because of the rapid equalization of pressure around them, smoke stacks are surprisingly resistant to blast. They often remain standing when adjoining structures are leveled to the ground. On the other hand, flat surfaces, such as windows and doors, in an extensive wall, will tend to give way very easily.

6.09. The rapid failure of window panes, light siding, and other flat, weak portions of a structure is often advantageous. When such failure occurs in a very short space of time, there will be a tendency for equalization of the pressure inside and outside the building. This reduces the destructive effect of the blast on the structure as a whole.

6.10. These general remarks apply to the effects of air blast from explosions of all types. The atomic bomb introduces an additional factor because of its tremendous energy release and the long duration of the blast wave. This is something like a second, as compared with a few thousandths of a second for an ordinary HE bomb. Thus, while a conventional bomb will affect only part of a building, the blast from an atomic bomb can engulf and damage whole buildings.

Height of Burst

6.11. In a weapon of such tremendous power as the atomic bomb, the height of burst is of great importance in determining the extent of damage. There are two obvious arguments in favor of detonating the weapon at an appreciable distance from the earth's surface. First, a bomb burst close to the surface is accompanied by cratering and melting of the ground, and hence there is a loss of energy from the blast. Second, an air burst avoids some of the shielding due to the presence of hills, and hence is more effective in covering uneven terrain.

6.12. On the other hand, it would appear that an undesirable feature of an air burst is the fact that the bomb is farther removed from the target than it would be if burst on the ground. However, in the case of an atomic explosion this is actually an advantage. The shock pressures in the vicinity of the burst are so high that they would overdestroy the target. This local overdestruction represents an unnecessary expenditure of energy in nearby parts of the target regions, thus decreasing the destruction inflicted on the more remote structures and matériel.

6.13. An appreciable height of burst is necessary to take advantage of the multiplication of shock pressure due to the Mach effect. As stated in paragraph 3.27, it appears that for a nominal atomic bomb a height of burst of 2,000 feet will cause the maximum over-all damage. The overpressures at and near ground zero are sufficient to render useless strong equipment and structures. While at the same time, weaker objects, such as parked aircraft and dwellings, are more or less severely damaged out to a considerable distance.

Direction of Blast and Shielding

6.14. A secondary effect of the height of burst is connected with the direction of the blast, and the somewhat related problem of shielding. Assuming a moderately high air burst, say about 2,000 feet, the direction of the blast striking a building near ground zero will be almost vertical (fig. 6.14a). At a distance however, the direction will approach the horizontal

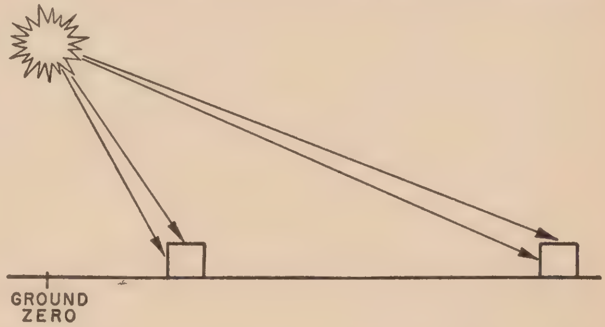


Figure 6.14a. In an air burst, the blast pressure on a building near ground zero is mainly on the roof; further from ground zero the pressure is mainly on the walls.

plane. Consequently, near ground zero the blast will be mainly from above, and roof failures will be common (fig. 6.14b). Further away, the pressure will be largely on the walls (fig. 6.14c). In these circumstances the shape of the structure, as indicated above, may have some effect.

6.15. It is evident that because the blast wave is moving almost vertically near ground zero, there is little possibility of a building being shielded by the terrain. But, at some distance from ground zero, hills can provide partial shelter from the air blast

Figure 6.14b. Reinforced concrete structure less than 500 feet from ground zero showing downward acting forces of an air burst.

(fig. 6.15). It should be pointed out, however, that the protection is not complete. Since the air pressure spreads out as a wave of steadily increasing radius, some of the blast will reach the far side of the hill. In the case of ordinary HE bombs, a building or matériel can frequently be protected from the blast by another building. In the case of an air-burst atomic bomb, however, this will occur only in exceptional cases.

Underwater Shock

6.16. Because of the fact that water is relatively incompressible, the impact of the shock wave on a ship or an underwater structure is a sudden blow of tremendous force. Shocks of this kind have been experienced with noncontact mines and with depth charges. But, whereas the shocks caused by the latter are more or less localized, that produced by an underwater atomic explosion can act on the whole ship almost instantaneously. The effects may be considered as two-fold—first, there will be the direct effects of the shock on the vessel itself; and, second, there will be secondary effects due to components within the ship being set in motion by the shock.

6.17. An underwater shock is associated with rapid movement of the hull of a ship in both horizontal (sideways) and vertical (up and down) directions. The horizontal motion tends to cause distortion of the hull below the water line, and rupture of shell plating, thus causing leaks. The vertical motion, on the other hand, will set up vibrations which will severely stress the ship girder.

6.18. Within the ship, main feed lines, main steam lines, shafting, and boiler brickwork are especially sensitive to shock. Due to the effects of inertia,

Figure 6.14c. Heavy machine-tool shop more than 2,000 feet from ground zero showing failure of sidewall due to horizontal component of blast pressure of an air blast.

the supporting members or foundations of heavy components, such as engines and boilers, are likely to collapse or become distorted. Lighter or inadequately fastened articles will be thrown about

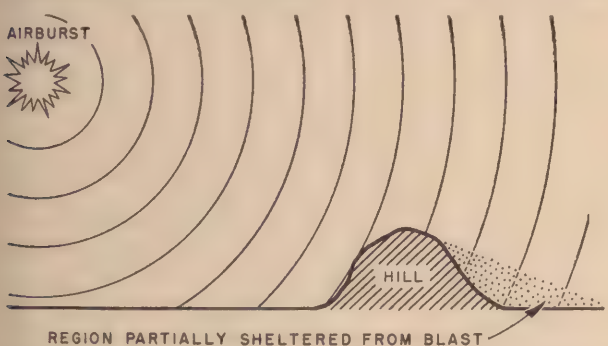


Figure 6.15. At some distance from ground zero, a hill provides partial shelter from blast due to an air burst.

with great violence, causing damage to themselves, to bulkheads, and to other equipment, and acting as a hazard to personnel. Articles which have been properly mounted against shock will probably escape damage.

Depth of Burst

6.19. In the case of the detonation of an atomic bomb in the air, it is not too difficult to estimate the height of burst which will cause maximum destruction on the ground. But, with an underwater burst, the situation regarding the depth of the explosion is much more complicated. If the target is on or near the surface, a ship's hull, for example, the direct shock will be followed very shortly by the arrival at the target of the reflected, rarefaction (suction) wave. The latter has the effect of cutting off the shock pressure and hence tends to reduce the amount of damage below the water line (par. 4.19).

6.20. It will be recalled (par. 4.21) that some of the energy of the underwater explosion appears as air blast. The proportion of energy that goes into blast is greater for a shallow explosion than for a deep one. There will thus be less underwater damage in the former case, but this will be compensated for to some extent by greater blast damage to the superstructure of a ship and to buildings on shore.

6.21. Another complicating factor is the depth of the water, and the participation of a shock wave reflected from the bottom. An analysis of the situation, based on the somewhat limited knowledge of underwater atomic explosions, indicates that, on the whole, the maximum damage radius to ships could be attained by a fairly deep explosion in deep water.

Underground Shock

6.22. As far as underground shock is concerned, an atomic explosion will be similar to the detonation of a buried mine, except for the much greater energy release. In some respects, the shock from an underground atomic explosion and the resultant damage may be compared to that of a moderate earthquake of shallow depth.

6.23. As stated in chapter 4, part of the energy of the atomic bomb in an underground explosion is divided between ground shock and air blast. If the explosion is a deep one, however, nearly all the energy will appear in the ground shock wave. But because the shock pressure falls off rapidly with increasing distance from the point of detonation, a deep burst might produce less structural damage at the earth's surface than a shallower one.

RADIANT HEAT AND FIRE

General Considerations

6.24. Heat and fire represent the second main cause of damage to structures and matériel due to the explosion of an atomic bomb. The thermal radiation accompanying an air burst (par. 3.37) strikes everything within several miles not shielded by intervening material. When this radiation falls upon an exposed surface, it is partially absorbed, and is immediately converted into heat. Because nearly all the radiant energy from an atomic explosion is delivered in the short period of less than 3 seconds, there is not sufficient time for the heat to spread from the surface into the body of the exposed object or material. Consequently, the thermal radiation from the atomic bomb causes exceptionally high surface temperatures.

6.25. It is due to these high temperatures that many substances will scorch, char, or even burst into flame. The actual effect will depend on the color and nature of the material, and the amount of radiant heat received. Typical products which are easily charred or burned are paper, wood, cloth, rubber, paint, and asphalt. Dark colored or dark painted materials absorb a larger proportion of the thermal radiation and so will char or burn more easily than those having a light color. Loosely gathered materials, such as piles of paper or rags, thin black draperies and curtains, and canvas tarpaulins may be set afire by the radiant heat from the bomb. Dry vegetation, such as dry grass or stubble, may also be ignited.

6.26. While thermal radiation may start many fires, a good proportion will be extinguished by the air blast wind which arrives seconds later. The situation will be different when a fire is started by the radiation in materials protected from the blast by glass or other transparent substance, for example, in the interior of a building or vehicle. Such fires may well continue to burn. In any event, in a built-up area numerous fires will be started by such blast effects as the overturning of stoves and furnaces, by the leakage of gas lines, and by electrical short circuits. The considerable number of fires, due to one cause or another, and their wide distribution will then make it difficult to get them under control.

Effects of Thermal Radiation

6.27. By means of certain laboratory experiments it has been possible to determine how much surface heat, similar to that due to thermal radiation from an atomic bomb, is required to produce various effects on materials. Then, by use of information such as that in figure 3.41, the limiting distances from an atomic explosion have been calculated at which these effects might be expected. Some of the results for the explosion of a nominal atomic bomb in the air at 2,000 feet are recorded in table 6.27; the distances are the maximum ranges from ground zero for the effects indicated. Because the transmission of the thermal radiation varies with atmospheric conditions, the distances are given for both a very clear day and a hazy day. For convenience in scaling these damage ranges to bombs of different energies (par. 3.42), the minimum quantities of heat, expressed in calories per square centimeter (cal./sq. cm.), required for the various effects are included.

6.28. It can be seen from table 6.27 that many basic materials used in supplies and equipment will be affected by the heat from the thermal radiation out to considerable distances from the explosion. The extent of damage depends on the nature and color of the material. Textiles of various kinds are sensitive; nylon melts fairly easily, while other fibres burn. Cotton materials, cotton twill in particular, seem to be relatively resistant to heat.

6.29. Products made from rubber, either natural or synthetic, will suffer various degrees of damage.

Table 6.27. Limiting Damage Ranges from Ground Zero for Thermal Radiation Effects in an Air Burst of a Nominal Bomb

Material	Effect	Heat energy required (cal./sq. cm.)	Limiting distance	
			Very clear day (yards)	Hazy day (yards)
Cotton shirting, khaki, 3.75 oz.	Scorches	6	2800	1650
	Burns	15	1750	1150
Cotton twill, khaki, 8.2 oz. (as used in summer uniforms).	Scorches	9	2300	1400
	Burns	15	1750	1150
Cotton, herring-bone twill, green, 9 oz (as used in combat uniforms).	Scorches	3	3900	2000
	Burns	17	1600	1050
Cotton duck, white, 7 oz.	Scorches	34	1150	800
	Burns	42	1050	650
Worsted, tropical khaki, 10 oz.	Nap scorches	9	2300	1400
	Burns	18	1550	1000
Wool gabardine, khaki, 14 oz.	Scorches	6	2800	1650
	Burns	23	1400	900
Wool gabardine, USAF blue No. 84, 12 oz.	Scorches	3	3900	2000
	Burns	9	2300	1400
Wool flannel, Navy blue, 11 oz (as used in undress jumpers).	Scorches	3	3900	2000
	Burns	9	2300	1400
Wool melton, Navy blue, 16 oz (as used in dress blues).	Scorches	3	3900	2000
	Burns	11	2100	1300
Wool serge, Navy blue, 14 oz.	Scorches	3	3900	2000
	Burns	9	2300	1400
Wool serge, Army olive drab, 18 oz.	Scorches	4	3400	1900
	Burns	15	1750	1150
Wool serge, USMC, green, 12 oz.	Scorches	3	3900	2000
	Burns	19	1550	1000
Wool elastique, USMC green, 19 oz.	Scorches	4	3400	1900
	Burns	35	1150	800
Wool kersey, USMC green, 16 oz.	Scorches	3	3900	2000
	Burns	32	1200	800
Wool kersey, Navy blue (as used in overcoats).	Scorches	3	3900	2000
	Burns	43	1050	650
Nylon, olive drab, 5.3 oz (as used in flying clothes).	Scorches	4	3400	1900
	Melts	8	2450	1450
Nylon, blue, 5.3 oz (as used in flying clothes).	Scorches	2	4500	2400
	Melts	7	2600	1550
Paper (white).	Chars	8	2450	1450
	Burns	10	2200	1350
Paper (brown kraft).	Burns	5	3100	1700
Douglas fir.	Chars	8	2450	1450
	Burns	11	2100	1300
Douglas fir (stained dark).	Burns	3	3900	2000
Philippine mahogany.	Chars	7	2600	1550
	Burns	9	2300	1400
Rubber (synthetic)	Burns	8	2450	1450

Heavy rubber coatings will experience only a superficial scorching, but thin coatings and sponge rubber will be seriously charred. Plastics and plastic glues generally do not stand up well to thermal radiation. For example, plastic parts may burn or fuse when rubber parts are only scorched. Plastic surface coatings and paints will show scorching, blistering, and discoloring.

6.30. The dependence of the damage range on the energy release of the bomb can be estimated from figure 3.44, which was given in chapter 3. The curves are for three different values of the thermal energy received on an average clear day: 3 cal./sq. cm. (causes moderate skin burns, black paper burns); 9 cal./sq. cm. (causes third degree skin burns, white paper burns); and 14 cal./sq. cm. (khaki cotton cloth burns). As pointed out in paragraph 3.45 the total amount of matériel, etc., affected by thermal radiation does not increase as rapidly as the energy release of the bomb, due to the nature of the scaling laws involved.

Primary and Secondary Fires

6.31. Fires accompanying an atomic explosion may be distinguished as primary or secondary, according to their origin. Primary fires are those caused directly by the thermal radiation igniting paper, thin cloth, rags, wood, dry vegetation, etc. Secondary fires are due to other causes, for which the blast is mainly responsible, such as upset stoves and furnaces, broken gas and other fuel lines, electrical short circuits, and so on. The evidence from Hiroshima and Nagasaki indicated that the great majority of fires were secondary in nature. Most of the primary

fires started by the thermal radiations were extinguished by the force of the blast. However, as mentioned above, this would not necessarily be true for inflammable materials protected by glass, etc.

Spread of Fires

6.32. No matter what the immediate cause, an atomic air burst over a built-up area will be accompanied by many fires occurring simultaneously, within a considerable radius. Once the fires have started, the chances of their spreading will depend on the combustibility and closeness of the buildings, the nature of the terrain, the weather conditions at the time of the attack, and the adequacy of the defense. In any event, by breaking glass windows and blowing in or damaging doors at stairways and elevators, and in fire-wall openings, the blast will make the interior of a building very vulnerable to the spread of fire. Airborne firebrands, entering through windows, doors and roofs, will cause the fire to spread from one structure to another.

6.33. Since fires are likely to start simultaneously on both sides, firebreaks may be unable to serve their intended purpose. In addition, if combustible material is strewn across the firebreaks and other open spaces by the blast, it may not be possible to prevent the spread of fire. It is considered that, in order to be at all effective, firebreaks should be at least 100 feet wide.

Fire Storm

6.34. When a large area is burning simultaneously, the phenomenon known as "fire storm" may develop. As a result of the huge masses of hot air and gases rising from the fire, air is sucked in with great force. Strong winds consequently blow from outside toward the center of the conflagration. The effect is similar to the draft that sucks up a chimney under which a fire is burning, except that it is on an enormously larger scale.

6.35. At Hiroshima, a fire storm, accompanied by winds of up to 30 or 40 miles per hour, developed about 20 minutes after the detonation of the atomic bomb. The strong winds blew toward the burning area of the city from all directions for 2 to 3 hours, decreasing to light or moderate and variable in direction about 6 hours later. Because of the strong inward draft at ground level, the fire storm prevented the spread of the fire outward beyond the range in which fires had started soon after the detonation. However, within this area virtually everything combustible was destroyed.

6.36. It should be understood that a fire storm is not necessarily characteristic of nor is it limited to atomic explosions. The occurrence of such storms depends on various conditions existing at the time of the fire. There was no fire storm over Nagasaki, for example; this was due partly to the nature of the terrain—the narrow valleys between hills, mentioned in paragraph 1.06—and partly to the direction of the wind. On the other hand, the great incendiary air-attacks on Hamburg and Tokyo, during World War II, were accompanied by fire storms. The phenomenon has also been observed in connection with large forest fires.

Fires Produced by Subsurface and Surface Bursts

6.37. In a subsurface burst, either under water or under ground, the thermal radiation from the exploding bomb will be absorbed almost entirely in the water or by the earth, and so its effect can be ignored. However, secondary fires, which are an indirect result of shock and blast damage, may occur, just as in the case of an air burst. The rupture of underground gas mains will probably cause many fires to start in a built-up area. On the whole, the fire hazard in an underground explosion will be similar to that after an earthquake. The spread of fires will depend on the kind of building construction, on the terrain, and on the meteorological conditions.

6.38. The effective range of the thermal radiation accompanying a surface explosion will depend on the nature of the terrain, as explained in chapter 4. In open terrain or at sea, where there is no protection from the radiant heat, the damage ranges will be much the same as, or perhaps greater than, those given in table 6.27 for an air burst. In a built-up area, however, a large proportion of the radiation will be obstructed and will not reach distant points.

6.39. Even though few fires may be initiated by the radiant heat, there will be many of the secondary type due indirectly to blast damage. If the explosion is fairly near the surface of the ground, a crater will be formed, and gas mains will consequently be broken, just as in an underground burst. The leaking gas may ignite and thus cause many fires to start.

As in other cases, the spread of fires will depend on local conditions at the time of the explosion.

6.40. In connection with the matter of fire damage, there is an important difference between a surface burst and those of other types. Since the ball of fire actually touches the ground in the former case, the bomb will cause direct ignition of everything combustible in its vicinity. Thus large fires will quickly start near ground zero, and will spread outward through the area destroyed and damaged by blast.

RADIOLOGICAL EFFECTS

General Considerations

6.41. It has been stated before that nuclear radiations, namely—alpha and beta particles, gamma rays and neutrons, unlike thermal radiations (radiant heat), do not affect materials in any visible manner. Thus, the essential value of the equipment, such as ship, tank, or gun, is not impaired. However, the radioactive contamination may be a danger to operating personnel (see ch. 7).

Sources of Contamination

6.42. There are two possible sources of radioactive contamination in an atomic air burst—first, radioactivity is induced in materials close to the burst by neutrons; and second, the residue from the bomb, consisting of fission products and uranium or plutonium that has escaped fission (par. 3.60). It is doubtful whether induced activity will be appreciable at distances greater than about one-half mile from ground (or surface) zero. Nevertheless, there is a possibility that materials containing sodium, for example, soap, table salt, and soil, or copper (or brass) may become radioactive due to the action of neutrons. The half lives of the resulting active species are both in the vicinity of 13 to 14 hours, so that, in each case, the activity will have largely decayed in 3 or 4 days. In general, neutron-induced activity is of little or no military importance.

Contamination in an Air Burst

6.43 As has been explained in Chapter 3, there will be no appreciable radioactive contamination on the ground or on a ship after an air burst. It is true that rainfall or abnormal meteorological conditions may carry down or cause depositions of greater than ordinary quantities of bomb residues (par. 3.63), but even under these exceptional conditions there will be no hazard to personnel on the ground.

Contamination in an Underwater Burst

6.44. Radioactive contamination of structures and equipment as a result of an underwater burst may be due to the deposition of particles both from the base surge and the water fall-out. A highly important aspect of this contamination is that it may be serious on a vessel or shore installation as far as 2 miles or more from the explosion of a nominal atomic bomb, where the energy of the shock and blast is almost completely spent. It is thus possible for a ship to be sound mechanically after an underwater atomic explosion, yet the radiological hazard to personnel may make its operation temporarily dangerous.

6.45. The sources of the residual radioactivity are particles of fission products and of the bomb material (uranium or plutonium) which has not undergone fission. The danger in handling or even approaching contaminated objects lies primarily in the harmful gamma radiation, although beta and alpha particles will be an additional, if minor, hazard.

6.46. The degree to which a particular material or object will become contaminated depends on so many variables that it cannot be predicted in advance. There are, nevertheless, two factors which have an important bearing on the problems of contamination and decontamination. First, a material with a rough finish is more susceptible to contamination than a smooth one, because the former has a larger over-all surface to which particles can adhere. Second, when a material is porous, the radioactive particles can penetrate under the surface and thus become difficult to remove.

6.47. Well-painted surfaces are smooth and nonporous; they are consequently not very susceptible to contamination. If the painted surface is worn or weathered, however, it becomes relatively rough and porous. Radioactive particles can then penetrate more deeply into the material. Similarly, clean and smooth metal surfaces are not easily contaminated, but metals are likely to corrode and the corroded

parts collect the contamination. Thus, rusty spots on metal, places where paint is chipped, cracked or roughened, and worn surfaces of wood are all areas which will become contaminated. Articles made of porous materials, such as manila line, nets, canvas and unpainted cork, are, of course, especially susceptible to contamination.

6.48. Concrete, unglazed brick, unpainted wood, and asphalt are porous, and buildings or roads constructed of these materials have a high susceptibility to contamination. Weathering and wearing will facilitate attachment of the radioactive particles. Unglazed tile surfaces are easily contaminated, but glazed tiles, on the other hand, have a smooth and nonporous surface which is resistant to weathering and contamination.

Extent of Contamination of Ships

6.49. The extent of radioactive contamination of a ship will depend, of course, on such external circumstances as its distance from surface zero, and the amount of time it spends in the base surge (par. 4.26). In addition, there are what may be called internal circumstances. If the weather envelope of the ship is intact, with all openings secured, and the ventilation system has been shut down while passing through the base surge, there should be little contamination below decks. However, if the base surge should gain access to the interior of the vessel, especially through the ventilation system, the consequences could be serious.

6.50. A secondary factor in determining the extent of contamination topside is the amount of cover available. While the base surge in its early stages is a mist or fog which moves outward and can envelop everything accessible, the radioactive fall-out and rain descend vertically. Objects and equipment protected from above will thus be somewhat less contaminated than those having no protection, or which are protected from the sides only.

6.51. The water from the fall-out and rain will continue after the base surge has thinned out, and will cover all topside surfaces. However, if there is good drainage, a large proportion may run off the vessel and carry away some of the radioactive particles. If any of this water penetrates below decks, it will, of course, transfer the contamination from the decks to the interior of the ship.

6.52. The water waves which might wash over ships will probably tend to decrease rather than enhance the contamination. This water will be considerably less radioactive than the base surge or fall-out, and hence it will wash away much of the contamination already deposited. Since the larger waves will begin to reach a vessel within the first 1 or 2 minutes after the explosion (see table 4.23), a good part of the activity from the base surge and fall-out will deposit subsequently. However, it has been found that the contaminating particles tend to adhere much less firmly to a surface already wetted than to a dry one. The waves produced by the underwater explosion may thus reduce the amount of radioactive contamination.

Contamination in an Underground Burst

6.53. The radiological effects of an underground burst will be similar, in many respects, to those of an underwater explosion. A base surge of dust particles, if formed, will contaminate everything it envelops. But how far or how fast such a base surge would travel is unknown. Because of the breaking of windows by the blast, it will be almost impossible to keep the contaminated dust out of buildings within about 2 miles or so of ground zero, assuming a nominal atomic bomb.

6.54. The contamination due to fall-out will be very great in and around the crater area. However, in this region all structures and equipment will be rendered useless, and the fact that they are also contaminated will not be of immediate concern. It should, nevertheless, be recalled that the crater region will be inaccessible for days, and it could not be occupied, even for short periods, until some time has elapsed (par. 4.63).

6.55. While many of the finer dust particles will remain in the air for some time, the larger ones in the fall-out will descend and contaminate the area near the explosion center. Since the particles can be carried by the wind, the total area covered by the fall-out may perhaps be greater than for an underwater explosion. But with increasing distance from ground zero, the intensity of the radioactivity will usually diminish rapidly, as explained in paragraph 4.60.

6.56. The general remarks made above in connection with the contamination by the base surge

and fall-out from an underwater explosion apply also to an underground burst. The only important difference is that while contaminated water will drain from higher to lower regions, and may, in some cases, largely drain away altogether, contaminated dust will tend to stay where it settles, unless carried away by the wind. In this connection it may be noted that special meteorological conditions could produce an exceptional contamination at certain locations.

6.57. In addition to the spread of contamination by wind, there is the possibility that it may be spread by human agencies, unless special precautions are taken. Persons moving out of a contaminated area could carry radioactive particles with them on clothing and other articles. Tracking by foot or, especially, by vehicles could also spread contamination. Further, heavy traffic would press the particles into road surfaces, making subsequent decontamination difficult, if not impossible.

Contamination in a Surface Burst

6.58. The contamination following a surface burst will have the same general characteristics as those associated with a subsurface explosion. While the base surge may be less pronounced in the former case, there will nevertheless be considerable fall-out. Since a surface atomic explosion presents no special features, as far as radiological effects are concerned, it is unnecessary to discuss it further.

EFFECTS ON LAND

Damage Ranges for Blast and Shock

Air Burst

6.59. Actual physical damage to structures and matériel on land will be primarily due to air blast and ground shock, with fire as a secondary development. As far as blast is concerned, it is possible, for atomic explosions, to associate a certain degree of damage with a particular peak overpressure of the air shock wave. From observations made in Japan and elsewhere, it is possible to make approximate estimates of the blast damage to structures and matériel to be expected at various distances from ground zero. The results in table 6.59 are for the air burst of a nominal atomic bomb at 2,000 feet altitude. The peak overpressures required to cause different degrees of damage are included. It should be noted that because of differences in building design and construction, even among structures of the same type, and because of the effects of meteorological conditions and terrain, the distances given in the table are to be regarded as approximate.

6.60. Severe damage, as applied to structures, means that the structure is either collapsed or has suffered to such an extent that it is beyond the possibility of repair. A moderately damaged structure is regarded as one which has been so badly damaged that it is unusable until repaired. Partial damage will not seriously interfere with the utility of the building; it may include loss of windows and doors, cracks in plaster and foundations, leaks in pipes, and partial stripping of roof material. Finally, light damage refers to cracking of plaster and breaking of windows.

6.61. As applied to matériel, severe damage in table 6.59 means that the item named is damaged seriously enough to render it useless and to make repair essentially impossible without removal to a major repair facility. Moderate damage is sufficient to prevent military use until repairs are effected, while light damage means that the object can still be used but it requires some repair to restore it completely.

Underwater Burst

6.62. For a moderately shallow underwater burst, such as that at the Bikini Test Baker, about a quarter of the bomb's energy would appear as air blast. The ranges for various types of damage on land would be about half those given in table 6.59. Thus, if the underwater burst of a nominal atomic bomb occurred more than a mile or so from shore, the damage to structures and matériel on land would be minor in character.

Underground Burst

6.63. The range for a particular type of damage in an underground burst, at a specified depth, will depend on the soil characteristics, and on the presence of rock strata which might reflect the shock wave. It is thus impossible to make any satisfactory estimate of damage ranges. Even if information were available from an actual underground atomic explosion, there would still be considerable uncer-

Table 6.59. Blast damage to various types of structures and matériel due to an air burst of a nominal atomic bomb at 2,000 feet altitud

tainty because of the nature of the soil and the depth of burst.

6.64. For a shallow underground burst of a nominal atomic bomb, the ranges for various types of damage due to air blast will be about the same as in the case of the shallow underwater burst, that is, about half the distances in table 6.59. The radius for ground shock damage will be approximately the same as that for air blast. Consequently, an underground atomic explosion is, in a sense, overdestructive, for essentially the same buildings will be destroyed and damaged by shock and blast. While the limiting damage range is probably between one-half and two-thirds that for an air burst, the over-all destruction within this range, especially near ground zero, will be much greater in the case of an underground burst. In addition, many subsurface structures and strong surface structures near ground zero, which would withstand the effects of an air burst, will succumb to an underground explosion.

Surface Burst

6.65. In general, the destructive effects of a surface burst may be expected to lie between those for an air burst and a subsurface burst. The damage ranges will be roughly three-fourths of those in table 6.59, with a relatively greater degree of destruction near ground zero.

Damage Range for Fire

6.66. Since the initiation and spread of fires will depend on such circumstances as the type of buildings and their contents, and on meteorological conditions, and the nature of the terrain, the fire damage range will be very variable. However, it may be expected, in general, that fire will spread to all structures which have suffered at least moderate blast or shock damage. This means that as a result of the air burst of a nominal atomic bomb, the fire damage range will be about $1\frac{1}{2}$ or 2 miles from ground zero. In a subsurface or surface burst the maximum range will be roughly a mile or more.

Range of Radiological Contamination

6.67. After an air burst the radiological hazard will be negligible, but the base surge and fall-out associated with subsurface and surface bursts may cause appreciable contamination of structures and exposed matériel as far as 2 miles crosswind from the center of the explosion. The distance will be considerably greater downwind, but less in the upwind direction. The degree to which any article or piece of equipment will become contaminated will also depend on its position and shape, on the nature of its surface, and on the degree of cover or protection provided.

Scaling Rules for Damage Ranges

6.68. The ranges for damage of various types given above refer to the nominal atomic bomb with an energy release equivalent to 20 kilotons of TNT. Although air blast and ground shock scale somewhat differently, it may be assumed, with a fair degree of approximation, that the distances are roughly proportional to the cube root of the energy release. For a bomb of W kilotons TNT energy equivalent, the range for blast or shock damage of any particular kind would be obtained by multiplying by $(W/20)^{1/3}$ the corresponding range for the nominal atomic bomb. This rule may also be used, in the absence of anything better, for assessing the range of fire damage and of radioactive contamination.

6.69. It should be noted, as has been pointed out previously, that the damage radius increases much less rapidly than the energy of the bomb. Thus, a five-fold increase in the energy release, from 20 to 100 kilotons TNT equivalent, changes the range for any particular type of damage by a factor of 1.7. If the structures, equipment, etc., were distributed more or less evenly about ground zero, the total area of destruction would be increased by a factor of $(1.7)^2$, i.e., 2.9. A five-fold increase in the energy of the bomb would thus mean only about a three-fold increase in the over-all damage.

Effects on Specified Structures and Matériel

6.70. The foregoing description of damage has been somewhat general in character. For defensive purposes it is necessary to know something of how individual structures and particular types of equipment are likely to survive an atomic attack. Consequently, the effects of blast, shock and fire on specific kinds of buildings and matériel will be outlined. Radioactive contamination will not be mentioned unless there is some special characteristic to which attention should be called, as with rations and water, for example.

Reinforced Concrete and Heavy Steel-Frame Buildings

6.71. While all types of structures can be damaged by sufficiently high blast pressures, some are less vulnerable than others. Reinforced concrete buildings and those with heavy steel frames are the most resistant types of construction (fig. 6.71). When partial failure occurs, for example, buckling or collapse of roof and floors, or fracture of columns, the undamaged members can often still carry the whole weight of the structure. In these circumstances, complete collapse will not occur, and the damaged portions of the building are more likely to distort than to break.

6.72. Reinforced concrete buildings are also the most fire resistant, for the concrete protects the steel structural members from the heat. However, if the contents of the building are combustible and continue to burn intensely for some hours, the concrete can crumble and thus expose the reinforcing steel. This may then be weakened by the heat and the building may collapse.

6.73. Because the strength of the steel members decreases markedly at moderately high temperatures, steel-frame buildings of all types are susceptible to serious structural damage by fire. As in the case of reinforced concrete buildings, the nature of the contents and interior construction is important in determining the extent of damage. If the structure has wooden walls and floors or contains combustible stores, the heat from the fire will cause steel members

Figure 6.71. Reinforced concrete building, 240 yards from ground zero in Japan. The walls are intact although the interior was destroyed by fire.

to weaken or to fail. Complete collapse of the building is then probable.

Light Steel-Frame Buildings

6.74. Many industrial buildings, repair shops, etc., have relatively light steel frames. In such buildings, fracture of supporting members and joint connections is not common, but the lightness of the frame makes mass distortion probable (fig. 6.74). Sheathing of corrugated iron or asbestos sheet is likely to be blown off, leaving only the frame standing. If such sheathing offers little resistance to the blast, the frame will suffer little or no structural damage. However, the contents of the building may be rendered useless by debris. The remarks made above with respect to the effect of fire on steel-frame buildings apply equally here.

Masonry and Brick Buildings

6.75. Heavily constructed masonry buildings may stand up well to blast because of their great size and weight. But, when the pressure is large enough to cause such a structure to distort slightly, or to fail locally, e.g., by breakage of mortar connections, the whole building may collapse. When such a masonry building does fail, the heavy structural material will cause severe damage to equipment and supplies in the interior. Light masonry and brick structures have little resistance to blast. The debris will bury equipment in the building, and will provide missiles which will injure persons in the vicinity.

6.76. Brick and masonry buildings with load-bearing walls if close enough to ground zero may be destroyed by the blast. If they are, the question of structural damage by fire is not important. However,

Figure 6.74. Light steel frame industrial building, 600 yards from ground zero in Japan. The roof and wall sheathing was stripped by the blast, and the combustible contents destroyed by fire.

fire can contribute to the damage independently by weakening the remaining supports, thus encouraging collapse of the building, and can add to the over-all destruction by consuming the contents.

Wooden Buildings

6.77. Owing to their light construction, wooden buildings have little rigidity and are easily deformed by air blast pressure. The nailed joints are relatively weak and can withstand little strain. Consequently, wooden buildings will quickly collapse as the result of an air burst. Even when they are beyond the range of severe destruction, they may suffer damage to roof, wall panels, and interior partitions. Stores and equipment inside the buildings are less likely to be damaged by the light debris, but, on account of the inflammability of the wooden structural material, they are more susceptible to destruction by fire.

Bridges, Highways, and Railroads

6.78. By virtue of their design, bridges are, on the whole, remarkably resistant to air blast. It was found after the atomic bombings of Japan that steel-girder bridges with reinforced concrete decks suffered relatively little (fig. 6.78). Even when there was some damage, such as destruction of road surface or shifting of the decks, they generally remained usable. In a few instances only was a span blown off its piers or abutment. However, an underground or surface burst would probably have proved more destructive. Long-span suspension bridges will stand a good chance of surviving an air burst because of their

Figure 6.78. Steel plate girder railway bridge, about 280 yards from ground zero in Japan. The plate girders were moved about 3 feet by the blast, but the bridge was essentially intact.

flexibility. Steel military bridges may be expected to resist blast almost as well as the permanent type. Emergency bridges of makeshift construction will probably not stand up well to an atomic explosion.

6.79. Highways, railway roadbeds, and rails are, on the whole, relatively invulnerable to damage by air blast. They may be covered by rubble and debris, but this can be removed. Even after a nearby surface or underground burst highways and railroads can be restored to operation without difficulty, if necessary by bypassing the severely damaged area. Railway rolling stock has the same vulnerability as other structures of a similar type.

Airfield Runways

6.80. Runways of airfields are built to withstand considerable pressure, and will probably not be seriously damaged by blast in an air burst. However, they may be expected to suffer severely from a surface or underground burst in the vicinity.

Tanks

6.81. Medium and heavy tanks and armored cars are very resistant to blast, shock, and thermal radiation. However, exposed equipment such as antennas, sighting mechanisms, lights, and machine-gun mounts are vulnerable. Tanks that are not properly buttoned up will suffer severe interior damage due to the entrance of the blast wave through ports and hatches. Near to the point of burst, such damage may occur even when the tank is buttoned up. The blast wave can then break through motor ventilation openings and the inspection plates between the motor and fighting compartments. The pressure build-up may blow hatch covers open. Furthermore, the blast wave may throw the tank some distance or overturn it. However, in spite of the possibility of damage, a medium or heavy tank will, in general, provide much protection against the effects of an atomic air burst.

Ordnance and Ammunition

6.82. While heavy weapons are somewhat more easily affected than heavy tanks, they are still very resistant to damage. Nevertheless, as with tanks, exposed parts, such as fire control equipment, will suffer. Ammunition is not as vulnerable to heat as might be expected. While exposed powder, such as artillery and mortar powder increments, can be ignited by thermal radiation, enclosed or encased ammunition is fairly resistant. Neither artillery shells nor small-arms ammunition will be affected by thermal radiation except, of course, near ground zero.

Vehicles

6.83. Essentially all types of vehicles, including jeeps, trucks, etc., and other mobile equipment will be subject to considerable damage due to direct action of the blast and shock or as a result of destruction of surrounding buildings. Overturning of vehicles or bumping of one against another will be contributory factors. Light damage will include breakage of windows, electrical equipment, and wiring, and infiltration of dirt or grit into the working parts of engines. Nearer to ground zero, wheels, exposed parts of the motor such as spark plugs and carburetors, tires and the body, may suffer in addition. In zones of heavy damage, there may also be warping of frames, collapse of roofs, and rupture of fuel tanks. In the latter event, ignition of the gasoline may result, and then there will be much fire damage. Thermal radiation may cause superficial damage to tires, paint, etc., but it will not ignite gasoline unless the tank is ruptured.

Electrical and Electronic Equipment and Machinery

6.84. Lightly constructed sensitive equipment, like switchboards, radar and radio sets, telephones, and radiation detection instruments, are highly vulnerable. Even if they are not directly affected by blast or shock, they can be ruined by debris or fire. Heavier equipment, for example, machine tools, motors, and generators can also be damaged by debris and by fire. Valuable industrial equipment, even if undamaged by blast, debris, or fire, can be rendered useless by rust due to exposure to the elements (fig. 6.84). Consequently, machinery of all kinds will suffer less in reinforced concrete or heavy steel-frame buildings than in light metal or wooden construction.

Public Utility Lines

6.85. Poles carrying overhead power and telephone lines are vulnerable to blast, shock, and fire and may be seriously damaged. The lines themselves may be blown down by the blast beyond the distance where the poles are more or less intact. Water and gas distribution lines running above the surface may suffer

Figure 6.84. Machinery lightly damaged by debris and by fire, but exposed to the elements after the atomic attack on Japan.

breakage, either due to the air blast or to the destruction of the buildings through which they pass.

6.86. In the case of an air burst, underground distribution lines usually will be undamaged, except directly below the burst, where ground shock may be responsible for damage to sewer pipes and drains at shallow depths. Damage to buried pipes and fittings may result from the weight of the debris on the ground above them.

6.87. All underground utilities will suffer greatly from the displacement of the ground and the shock pressure due to a subsurface explosion. Sewer, gas and water mains will be particularly susceptible. It is possible that electric mains will suffer much less because of their ductility. However, above-ground lines may be broken as a result of tower and pole distortion, caused by the earth shock.

Supply Dumps

6.88. Supply dumps have little exterior protection and are therefore subject to considerable damage and destruction by blast, shock and fire unless dug in as described in paragraph 12.30. Gasoline and oil dumps will be particularly vulnerable, because rupture of containers may well be followed by serious fires. Ration and ammunition dumps will, on the whole, probably suffer less severely unless fire breaks out.

Rations and Water

6.89. In the event of an air burst, rations which survive the blast and fire should generally be usable. But after a surface or subsurface burst special precautions will have to be taken against the possibility of radioactive contamination. Unpackaged food

which has been in direct contact with the base surge or with the fall-out will be unfit for consumption. However, if there was no actual contact with the food itself, it will be unaffected. The radiations as such can do no harm to food. It is only when the radioactive particles are on the food, and can thus enter the body, that there is real danger. Canned and packaged goods are not affected in any way. Provided contamination, if present, can be washed off the exterior without risk, and the hands are clean, the contents may be safely consumed.

6.90. Potable water supplies, if exposed, may become contaminated, but not necessarily to a dangerous level. However, if stored in closed tanks the water will be safe for consumption. Due care must, of course, be taken to prevent the water from becoming contaminated by subsequent handling.

EFFECTS AT SEA

Damage Ranges for Shock and Blast

6.91. All the information concerning the effects of atomic explosions on ships was obtained from the tests at Bikini, where many of the vessels were of obsolete types, and were, in any case, riding at anchor. From these observations certain conclusions have been drawn concerning what might be expected from modern vessels. While these are often only intelligent guesses, they are worthy of consideration. In the discussion which follows, thermal radiation is not mentioned. The Bikini tests indicated that it would not be an appreciable factor in producing damage at sea, since the exposed portions of naval vessels are practically fireproof. However, this does not exclude the possibility of secondary fires involving such combustibles as gasoline or explosives where there has been extensive blast damage.

6.92. The approximate limiting distances from surface zero at which various degrees of damage may occur to ships and their equipment, from an air burst and a moderately shallow underwater burst, are given in table 6.92. This refers to a nominal atomic bomb. For purposes of comparison with effects of an air burst on land, the distance scale in table 6.92 is in intervals of 500 yards, the same as in table 6.59. A comparison of blast damage at sea and on land, for an air burst, is also given in figure 6.92. Severe damage implies that the ship will be sunk or damaged to such an extent as to completely lose its military effectiveness; moderate damage means immobilization and probable flooding of at least one primary compartment; light damage refers to damage to electronic and other light equipment. It is of interest to note that beyond about 1,500 yards from surface zero only damage of a minor character should be experienced at sea.

6.93. In scaling for the effects of bombs of different energies, the cube-root rule may be used to calculate the damage ranges for an air burst. The various distances in table 6.92 should thus be multiplied by the factor $(W/20)^{1/3}$. For an underwater burst, where the damage is largely due to shock, rather than to blast, this factor would probably underestimate the damage range. If scaling is necessary it would be advisable to use the factor $(W/20)^{1/2}$. The range of appreciable contamination on ships due to the base surge and fall-out following an underwater burst, will be the same as given in paragraph 6.67, that is, about 2 miles crosswind from the center of the explosion and still farther in the downwind direction.

General Effects of Blast and Shock on Ships

6.94. Ships as a whole are remarkably resistant to blast damage. This follows from a consideration of the requirements which must necessarily be built into a seagoing vessel. For example, a considerable portion of the topside area of a combatant ship is built to withstand blast from the firing of its own guns. The hull proper is required to withstand impact of waves, as also are portions of the superstructure. Furthermore, many important stations are protected by armor or splinter shields, which are strongly built.

6.95. The design and materials of construction permit deflection and yielding without rupture. In addition, the ship is floating in water and can yield as a whole (by rolling or heaving) without sustaining any damage due to this motion, whereas a structure of comparable size on land would be damaged by the very act of moving the entire assembly relative to its foundations.

6.96. Orientation and shape of structure will have a considerable influence on damage. Surfaces nearly parallel to the direction of burst will be damaged less than those more nearly perpendicular to it. In some locations not exposed to the direct blast, damage will result from the combined effect of deflection and re-

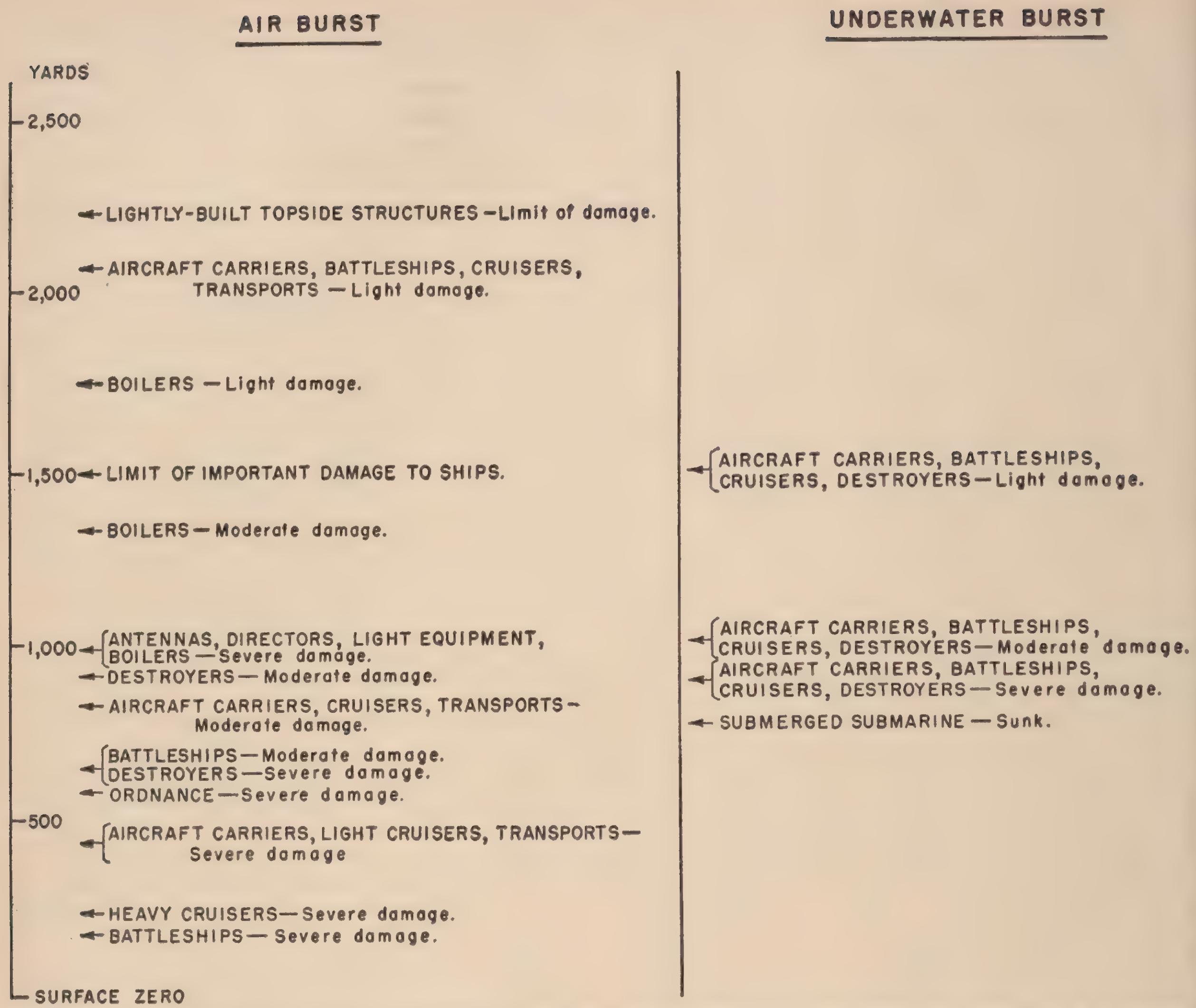


Table 6.92. Comparison of damage ranges to ships, due to air burst at 2,000 feet altitude and shallow underwater burst of a nominal atomic bomb.

flection of the blast wave from exposed surfaces into pockets or dead ends under overhanging structures, gun sponsons, etc.

6.97. On ships having large exposed deck areas, such as the well decks of older type cruisers, quarter-decks of battleships, cargo-handling decks of merchant-type vessels, the decks may be deformed as a result of blast pressure. The main strength watertight hull will not be affected materially at ranges greater than 600 yards from the explosion of a nominal atomic bomb. This approximate limit applies to both air bursts and underwater bursts. For an underwater burst at ranges up to about 600 yards the underwater shock is sufficient to cause direct rupture of the hulls of most vessels, due to the effects previously discussed in paragraph 6.17. For an air burst, at distances closer than 600 yards the strength hull may be distorted above the water-line sufficiently to initiate cracks which will progress to below the water-line and permit extensive flooding. On light aircraft carriers, warping and buckling of flight decks probably will occur to about 700 yards (fig. 6.97). It is possible that the airplane elevators will be dislodged from their position, and it is still more likely that the distortion of the deck and resulting misalignment will render operation of the elevators impossible.

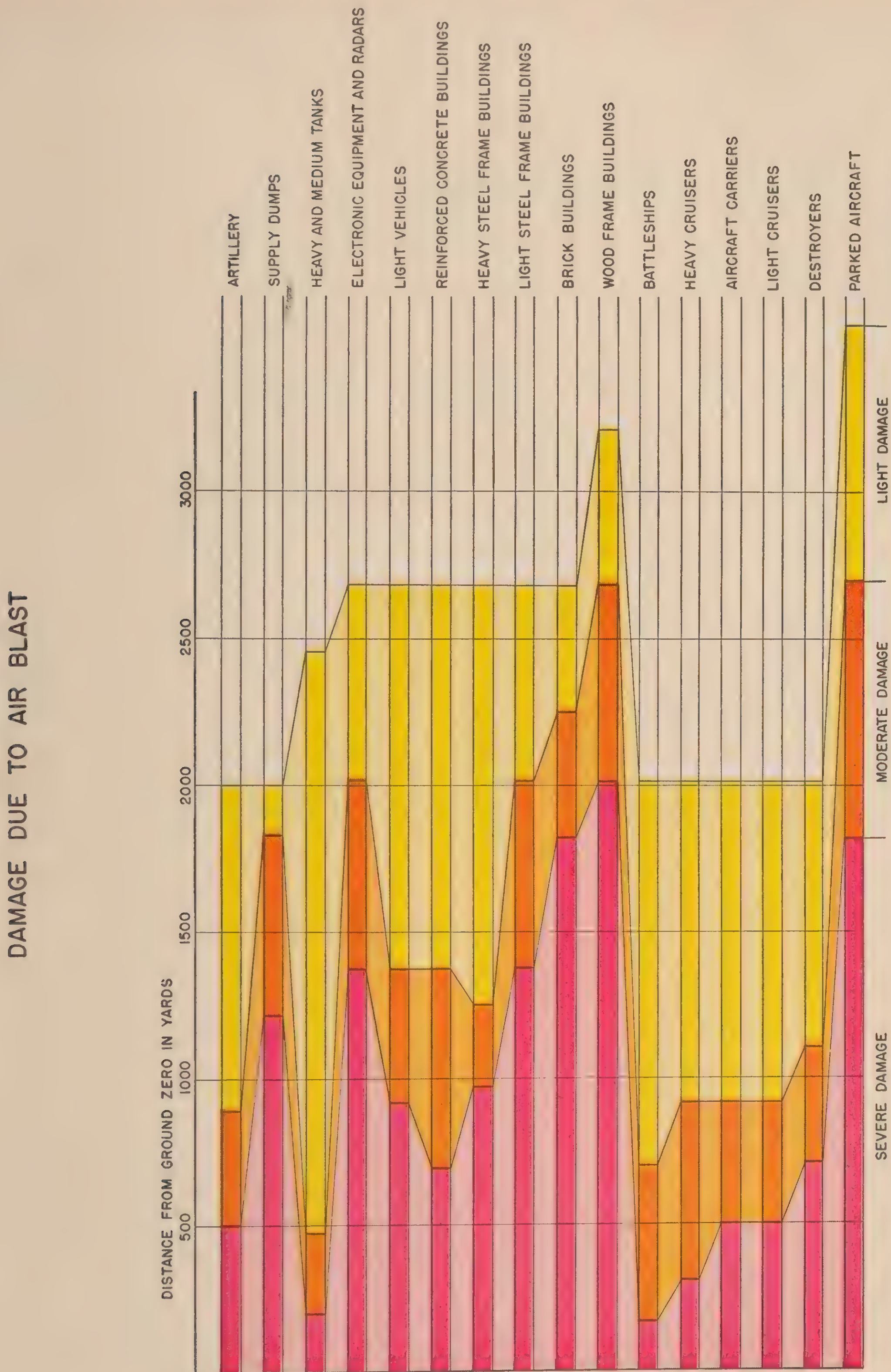


Figure 6.92. Comparison of damage ranges of structures, equipment, ships, and aircraft due to air burst of nominal atomic bomb at 2,000 feet altitude.

Figure 6.97. Flight deck of carrier INDEPENDENCE looking aft from the island after Test Able. In this case the blast pressure entered the hangar deck from the side, through rupturing of side curtains. Consequently, the flight deck was bulged upwards whereas the hangar deck below was dished downwards. This vessel was within one-half mile of surface zero.

Effects on Specific Parts of Ships

Topside Equipment

6.98. Masts, rigging, cargo-handling gear, and boat-handling equipment will suffer distortion due to blast. The latter may be disarranged and severely damaged if improperly secured. Antennas of all kinds, except those of the whip type, will be seriously affected due to dislodgment as a whole, distortion of the coaxial cable, or misalignment due to distortion of masts, etc.

6.99. Stacks may be damaged both by distortion and by dislodgment as a whole. The most modern ships have stacks strengthened by reduction of projected area and a slight increase in plating weight. Due to their shape, stacks are relatively resistant to blast damage considering the normal weight of the material used in their construction.

Doors

6.100. Water-tight doors and their points of installation in bulkheads are points of weakness. Unusually large deflections are liable to occur in their vicinity, as a result of either blast or shock. These deflections are such as to cause misalignment and consequent inoperability of the door.

Interiors

6.101. Air blast penetrates all openings, through broken bridge ports, open doors, hatches, and venti-

lation openings. Damage caused will be similar to that produced by gun blast. Ventilation ducts will be bulged and ruptured when closures are not in place over the exposed exterior openings.

6.102. In light superstructure compartments some damage may be expected where instruments and fittings are mounted on bulkhead plating. This is due to the transient deflection of plating under blast. Where electronic equipment is mounted with insufficient clearance, some secondary damage may be expected from the bulkhead striking the equipment. Much equipment secured to these bulkheads will be torn loose.

Machinery

6.103. No appreciable damage will be caused by air blast to machinery components on vessels which survive, except for boilers and as indicated below. Blast will be channeled down the stacks and bulge the boiler casings causing some air leaks. In most cases these could be repaired by ship's force. If boilers are in operation, flarebacks are likely. Deck machinery may suffer missile damage in a few instances. In regions where decks are distorted, difficulty will be experienced from misalignment of deck machinery.

6.104. Of all vital ship components, machinery is most susceptible to underwater shock. Damage to foundations of heavy equipment may cause serious misalignment and rupture of connected piping. For an underwater burst of a nominal atomic bomb, such damage to main propulsion and auxiliary machinery can render the vessel inoperable out to a range of at least 800 yards. Hence, it is this type of damage, rather than direct rupture of the underwater hull, which determines the range of critical damage due to underwater shock.

6.105. It is probable that the damage to machinery will be intensified if the ship is under way. Some equipment requires close tolerance in alignment and clearance, and integrity of foundations. Thus, heavy shock may render such machinery useless. For example, it might be possible for reduction gears and the propeller shafts to wreck themselves completely.

Piping

6.106. As stated previously, certain pipe lines, particularly the main feed and main steam lines, are especially liable to damage by shock.

Ordnance

6.107. Since ship armament is specifically designed to withstand great pressures, there will be little damage due to blast. The insides of the gun turrets will not be affected at such distances from the explosion that the ship is still operable. Under these conditions there is also little danger of powder or ammunition exploding. Fixed ammunition at open antiaircraft gun mounts will probably be safe during an air burst.

6.108. Underwater shock will damage holding-down clips and gun elevating mechanisms, and may displace heavy gun mounts from their foundations. Plotting rooms and their equipment may be rendered inoperable. Ammunition stowages will be damaged, and projectiles and powder cans will be torn loose and scattered. These will represent a missile hazard both to personnel and equipment.

6.109. With regard to military efficiency, the most serious effect on gun and torpedo armaments, as the result of an atomic explosion, will be due to reduction of fire power through damage or destruction of radar antennas and directors.

Effects on Carrier-Based Aircraft

6.110. Aircraft spotted on flight decks will be injured by blast in an air burst just as they would be on the ground. The nature of the damage suffered is recorded in some detail below. In the case of a light aircraft carrier, damage to the vessel may permit entry of blast and thus cause destruction of planes stored in the hangar space.

6.111. Damage from an underwater burst to aircraft aboard a navy carrier would arise largely from the sharp underwater shock which is transmitted through the ship's hull to the aircraft. This shock travels through the aircraft landing gear to the fuselage framework and wings causing severe to moderate damage to these assemblies. Bent landing gear struts, buckled fuselage and wing panel, and twisted wing spars especially near the wingtips can be expected.

6.112. The water waves accompanying an underwater burst might sweep planes overboard from carrier decks. However, at the distances from the explosion at which this could occur, the carrier itself would be seriously damaged.

Contamination of Ships and Equipment

6.113. In general, everything on a ship that has come into contact with the base surge or has been wetted by the fall-out and rain will be contaminated. This means that all topside surfaces of such a ship, its deck machinery, and exposed surfaces of topside armament equipment will inevitably have radioactive particles deposited on them.

6.114. After Test Baker at Bikini, it was found that upper works often retained more of the contaminants than did the lower parts of a ship. The reason for this was that when water deposited on the topsides of ships drained off over lower structures to the sea, it exercised a washing action, removing some of the contamination of those structures.

6.115. The contamination of interior portions of a ship, whether they are above or below decks, depends entirely on the air and water tightness. Entry of the base surge will cause the most serious situation, especially if it is sucked in by the ventilating fans. The radioactive fog will contaminate all accessible surfaces. Water from the fall-out and rain could also be a source of contamination. But the effects will not be so widespread, unless the ship is badly damaged and the water enters in many places.

6.116. Although there is a possibility of achieving at least partial emergency decontamination of the topside of a vessel while it is still at sea, it is more difficult to do so in the interior. It is consequently of the utmost importance to try to prevent or restrict the radioactive contamination of the interior of a ship. It should be remembered that even some time after the explosion, radioactivity could be distributed over the interior of a ship by lack of precautions on the part of personnel, whose clothing had become contaminated. Tracking of water below decks from topside may be expected to contribute to the spread of contamination.

Contamination of Air Passages

6.117. Because of the desirability of avoiding, or at least minimizing the time spent in the base surge, a ship should be traveling as fast as possible. In these circumstances, large quantities of combustion air will be required by the boilers. Fortunately, in modern boilers this air is delivered from outside direct to the boiler casing and burner registers, and not into the fireroom as was the case in older installations. A large proportion of the entrained contaminants entering the boiler while steaming through the base surge will be ejected in the stack gases, but some may remain in the boiler uptakes, especially in the economizers. At the same time, forced draft blower rooms may become contaminated.

6.118. Since the target vessels at Bikini were stationary, there is no experience upon which to base any estimate of the degree of contamination that might be expected through boiler air systems under operational conditions. Although the radioactive material will be on the inside of the boiler casings, etc., a large proportion of the gamma radiation will penetrate through the metal and may be a hazard to personnel. By the use of instruments, however, it will be possible to determine how long an individual can remain in a fireroom without taking undue risks.

Contamination of Water and Rations

6.119. Unless evaporators are secured immediately upon entering an area of contaminated water, there is a possibility that radioactive particles will be carried over into the distillate and ultimately find their way into the potable water tanks. If a sufficient concentration is built up it might be a hazard. The remarks made in paragraph 6.89 with regard to the contamination of rations on land apply equally at sea.

EFFECTS ON AIRCRAFT

General Considerations

6.120. Aircraft are designed to withstand the great stresses and loads experienced under actual flight conditions. These are quite similar to the effects produced by the blast in an atomic explosion. Consequently, in spite of their apparently light construction, planes have inherent characteristics which give them some resistance to blast. In addition, airplanes are built to withstand the shock of landing, and consequently a certain degree of shock-resistance is incorporated in the design.

6.121. Because of the nature of their mission, the smaller fighter-type planes, and jet fighters in particular, are designed for high loads and accelerations with a minimum of surface area. Therefore, such aircraft will be inherently much less susceptible to blast damage than larger aircraft, such as bombers and cargo planes, which expose a relatively much

greater surface area. Such items as the vertical stabilizer and broad-sided fuselages of these planes present large areas to blast effects.

6.122. The more vulnerable components of an airplane are—Plexiglas, particularly flat plates and canopies; fabric surfaces, which are susceptible to rupture and burning; control surfaces, monocoque or semimonocoque elements of fuselage; and most cowling.

6.123. Damage to equipment and accessories of an airplane will depend largely on whether the blast reaches the interior. The smaller aircraft have few openings and if the skin and frame remain intact they will protect the equipment, whereas larger aircraft with their numerous large openings are likely to receive considerable damage to equipment. It is to be expected that since aircraft in flight are normally buttoned up, interior damage from blast will usually occur only to parked aircraft.

Aircraft in Flight

6.124. Airplanes flying within 1,500 yards of the point of detonation of an air burst of a nominal atomic bomb at the time of the explosion will probably suffer severe damage. Some damage can be expected out as far as 3,000 yards. In this respect, however, it should be noted that aircraft in flight will normally be above the altitude of the Mach effect (par. 3.24) and consequently the radius of damage due to air blast should be significantly less than for aircraft parked on the ground.

Parked Aircraft

6.125. In addition to damage from direct air blast, parked aircraft may be damaged by being lifted entirely off the ground, by tipping onto a wing, or by overturning. The tendency to weathercock and the resultant violent whip may cause damage to fuselage and tail structures, which are not designed for very much of this particular type of stress. The larger aircraft will be more susceptible to the foregoing types of damage, due to their greater surface area and lower wing loading. A further source of damage to parked aircraft is by flying debris.

6.126. Inasmuch as parked aircraft often have openings by which the blast wave may enter the aircraft, damage to light interior equipment such as electronic devices and flight instruments is possible. However, it is likely that the aircraft as a whole will suffer serious damage before any of the heavier interior items, such as oxygen, hydraulic, fuel and oil systems, and armament, suffer appreciably. Table 6.126 gives a general approximation of the damage ranges and types of damage for parked aircraft resulting from a 2,000–foot air burst of a nominal atomic bomb. This table is based on the Bikini tests, but the ranges have been corrected to take into account the fact that the actual height of burst of the Bikini Able shot was less than 1,000 feet.

Table 6.126. Damage Ranges for Parked Planes from Air Burst of a Nominal Atomic Bomb

(Distances are from Surface Zero)

Severe Damage	Moderate Damage	Light Damage
0–1,800 yds. Smashed canopies and control surfaces. Buckling and breaking of monocoque and semimonocoque fuselages; split wing tanks; significant damage to airfoils.	1,800–2,800 yds. Severe damage to light structural components. Dished cowling and missing cowl flaps. Dished in and buckled fuselages and wing tanks. Dished skins on wings, but no damage to framing of heavier structural components.	2,800–4,000 yds. Damage to light components. Little or no damage to intermediate and heavy structural components.

Contamination of Aircraft by Atomic Cloud

6.127. While there is little or no risk of contamination at the ground level after an air burst, an aircraft flying through the atomic cloud will pick up a certain amount of radioactive residue. The degree of contamination will be greater if the passage through the cloud occurs soon after the explosion. In these circumstances, too, the crew could receive a considerable dose of radiation while traversing the cloud, apart from that which they might subsequently acquire from the contaminated aircraft. The matter of the exposure of the crew will be considered in chapter 7. It should be emphasized that radioactive contamination in no way affects the mechanical performance of a plane, its engine, or any of its equipment. It is objectionable only as a potential health hazard to operating and maintenance crews.

6.128. As a result of flying through a radioactive cloud, an aircraft may be contaminated to some extent on its exterior surfaces, in the interior, and especially within the engine. Contamination of the surface will be greatest where there are abrupt changes of contour. The leading edge of the airfoils, turrets, or places which are usually dirt collectors, and oily surfaces, are most likely to be heavily contaminated.

6.129. Engines will become contaminated by the stream of air that passes through them while they are operating. Air intakes, oil cooler, carburetor air ducts and throat, and superchargers, are thus regions where considerable contamination may be expected. If carburetor air filters are in operation, they also will be subject to heavy contamination. However, it is preferable to have the filters contaminated, rather than the engines, since it is difficult to decontaminate the latter. Carburetor air filters might thus be turned on for the purpose of acting as collectors, and so reducing the contamination within the engine.

6.130. Jet engines present a special problem. The air intake of such an engine is roughly 100 times that of the ordinary reciprocating engine, and consequently the possibility of contamination is greatly increased. Although this contamination probably would not represent a hazard to air crews, due to the relatively short exposure time involved, precautions would have to be taken to avoid subsequent excessive exposure on the part of ground maintenance crews.

6.131. Airborne contamination may occur in the cabin, turrets, etc., in the interior of a plane. Although this will usually be small, it should be pointed out that breathing air containing radioactive particles might prove injurious as a long-term radiation hazard to the operating crew (ch. 7).

SUMMARY

Damage to structures and matériel in an atomic explosion is due to blast and shock, and heat and fire. Fires may be started by thermal radiation, but most will be extinguished by the blast. The majority of fires will be secondary in nature, due to indirect blast effects.

While radioactive contamination does not cause any material damage, it can render a building uninhabitable or equipment unusable for some time because of the hazard to personnel. An air burst is noncontaminating and the only important radiological effect would be on an airplane flying through the atomic cloud.

The base surge and the fall-out accompanying a subsurface or surface burst will produce considerable radioactive contamination. In general, rough, worn, and porous surfaces will be more susceptible than smooth, nonporous surfaces. Clean metal and well-painted articles are least vulnerable to contamination.

Reinforced concrete buildings are resistant to blast, shock, and fire; heavy steel-frame structures withstand blast and shock, but fire weakens the steel members and may cause collapse. Light steel-frame, wooden, and brick buildings are vulnerable. Bridges are very resistant to blast. Underground shock will cause sewer, gas, and water mains to suffer severely, but electric mains will not be greatly affected. The rupture of gas mains may cause fires to start.

Vehicles are easily damaged, as also are lightly constructed electrical and electronic devices of all kinds. Heavy equipment, such as machine tools, motors, generators, etc., will be injured by debris and by fire. Medium and heavy tanks and armored cars are very resistant to blast. Heavy weapons also will stand up well. In all cases, however, exposed parts and equipment will suffer.

Naval craft are, on the whole, not very vulnerable to blast or shock. Fairly close to surface zero, hulls may be damaged by underwater shock. Topside equipment is likely to suffer from blast, and antennas are especially sensitive. No serious damage to machinery is expected from blast, but rupture of foundations due to shock will render it useless. Main feed and main steam lines, and boiler brickwork are also sensitive to shock.

Because of their design, aircraft, especially fighter-type planes, can withstand moderate blast and shock. Large planes have a considerable surface area exposed to blast; as a result they may suffer damage from tipping or weathercocking. The power plant, armament, and oxygen, hydraulic, fuel, and oil systems are resistant to blast. Interior equipment will be protected if the exterior of the craft is intact.

Chapter 7

EFFECTS OF ATOMIC EXPLOSIONS ON PERSONNEL

INTRODUCTION

Classes of Injuries

7.01. The injuries to personnel resulting from an atomic explosion may be divided into three broad classes, as follows:

(1) Blast and shock injuries.
(2) Burns.
(3) Nuclear radiation effects.

While nuclear radiation has attracted considerable interest, because it represents a new feature of warfare, it should be clearly understood that casualties due to this radiation are likely to represent a fairly small proportion of the total. In the atomic explosions over Japan, for example, not more than 15 percent of the fatal casualties were caused primarily by nuclear radiation. The remainder were due to various blast effects and to burns. For personnel shielded against blast and thermal radiation, the percentage of radiation casualties might be higher, although the total number of injuries of all kinds would be decreased.

7.02. An important aspect of the injuries in atomic explosions is the occurrence of what may be called "combined effects." Thus, a person not too far from ground zero may suffer from blast injury, from burns, and also from the effects of nuclear radiation. In this respect, radiation injury may be a complicating factor, since it is combined with injuries due to other sources. Apart from the nuclear radiation effects, most of the casualties suffered in an atomic explosion will not differ greatly in character from those accompanying ordinary HE and incendiary bombs.

Variation of Injuries with Operational Use of Bomb

7.03. In an air burst, the radioactive products of the explosion are raised to a great height in the atomic cloud, and they are dispersed over a large area. There is unlikely to be any appreciable fall-out of contaminated particles at any one place, and the hazard due to residual or lingering radioactivity will be negligible. Since an air burst is noncontaminating, the only injuries that will arise are those due to blast, burns, and the effects of the immediate nuclear radiations.

7.04. In a subsurface burst, there will be mechanical injuries due to shock and blast, and burns. The thermal radiation is almost completely absorbed by the water or the earth and, so, burns due to this cause will be insignificant. The immediate gamma radiation, emitted from the bomb at the time of the explosion, is also absent in a subsurface burst. But instead there may be a transit dose of radiation from the base surge as it passes by a ship or land area. In addition, contaminated water or dirt from the fall-out will settle on exposed surfaces, and cause continuing radiation effects. Hence, in an air burst, the danger to individuals, apart from those trapped in damaged or burning buildings, is over in a few seconds, while in the case of a subsurface or surface burst, the radiation hazard may continue for some time because of the lingering or delayed radioactivity.

INJURIES DUE TO BLAST EFFECTS

Primary Blast Injuries

7.05. The injuries caused by blast can be divided into two categories which are—(1) primary (or direct) blast injuries, and (2) secondary (or indirect) blast or mechanical injuries.

7.06. Primary blast injuries result from the direct action of the air shock wave on the human body. It requires approximately 100 psi to cause significant primary injury. An overpressure of this magnitude is not attained even at ground zero in the air burst of a nominal atomic bomb at a height of 2,000 feet. For purposes of comparison it may be noted that 3.5 psi will demolish a brick structure. Primary blast injuries, by themselves, are thus not important.

7.07. A form of primary blast injury which has not yet been properly studied is that due to noise from the atomic explosion. It is believed that the terrific noise heard by persons near the explosion might daze them, and thus contribute to a psychological, as well as a physical, hazard.

Mechanical Injuries

7.08. Secondary blast injuries are caused mainly by collapsing buildings, and by timber and other debris flung about by the blast, striking the body. Persons may also be hurled against stationary objects or

thrown to the ground by the high winds accompanying the explosion. The injuries sustained are thus similar to those due to a mechanical accident. They consist of bruises, concussions, cuts, fractures, and internal injuries.

7.09. At sea, the shock wave accompanying an underwater burst will produce various mechanical injuries. The casualties will resemble those caused aboard ship by more conventional underwater weapons, such as noncontact mines and depth charges, but instead of being localized, they will extend over the entire vessel. Fracture of the legs, due to the severe jarring of the ship by the underwater shock wave, may occur. There will also be mechanical injuries resulting from personnel being thrown against fixed objects or structures. In addition, equipment, furniture, gas cylinders, boxes, etc., which were not too well secured, or which have been torn loose by the shock, will act as missiles and cause many injuries.

7.10. As with mechanical injuries due to other causes, hemorrhage and shock are frequently serious complications. The importance of shock cannot be overemphasized, since it is often the main factor in determining the fate of the patient suffering mechanical injury. Consequently, the earliest possible attention should be given to treatment for shock. In this connection, simple first aid measures are of great value.

7.11. It should be noted that both primary and secondary blast injuries have been encountered after attacks with HE weapons. In other words, the atomic bomb does not present anything especially new in respect to the types of blast injury. The significant fact is the enormous number of injuries occurring in a limited area in a very short time due to the tremendous power and saturation effect of the atomic bomb (ch. 1). This emphasizes the need for widespread first aid training (par. 7.69).

7.12. In a city or other area where persons are in or around buildings, or on a ship, the frequency and the severity of mechanical injuries may be expected to follow roughly the pattern of structural damage. After the air burst of a nominal atomic bomb, incidence of death and severe injury from mechanical causes will be very high within approximately a half-mile radius from ground zero. Beyond 1 mile, the proportion of fatalities will decrease but mechanical injuries, although less severe, will still be numerous. At about 2 miles injuries will be still fewer; beyond 2 miles they will be less common and minor in character. The limit of notable injury will be about 4 miles from ground zero.

INJURIES DUE TO BURNS

Types of Burn Injury

7.13. It is convenient to divide burns due to an atomic explosion into two classes, namely—(1) primary burns, and (2) secondary burns. As in the case of blast injuries, the terms primary and secondary refer to the manner in which the burns are sustained. Those in the first class are a direct result of thermal radiation from the bomb, while those in the second group arise indirectly from fires caused by the explosion. However, from the point of view of their effects on the body and of their treatment, primary and secondary burns appear to be similar. They are also similar to burns produced in various other ways.

7.14. Burns are generally classified according to their severity, in terms of the degree (or depth) of the injury. In *first degree burns*, of which mild sunburn is an example, there is only redness of the skin. Healing will occur without treatment, and there is no scar formation. *Second degree burns* are deeper and more severe, and are characterized by the appearance of blisters. They are slower to heal, but do so eventually without leaving scars. Severe sunburn with blistering is an example of a second degree burn. In *third degree burns*, as may result from contact of the bare skin with a hot stove for a few seconds, the injury extends through the skin to the deeper tissues. Such burns heal slowly, and there may be scar formation.

7.15. The depth of a burn is not the only factor in determining its severity. The extent of the area of the skin which has been affected is also important. Thus, a first degree burn involving the entire body may be much more serious than a third degree burn at one spot. The larger the area burned, the more likely is the appearance of symptoms involving the whole body.

7.16. As with mechanical injuries, shock is commonly associated with extensive burns. In many instances, the occurrence and treatment of shock are important in determining whether the injured person

will recover or not. Burns are also subject to infection, and this may have serious consequences. Healing may be delayed or prevented, and may be accompanied by excessive scar-tissue (keloid) formation.[1] The general effect of the burn on the body may be aggravated by infection. A late and serious complication of extensive burns is anemia.

Secondary Burns

7.17. The characteristics of burn injuries described above apply, as stated earlier, to all types of burns, no matter how they are caused. Except for the large number of persons affected, secondary burns or indirect burns following an atomic explosion are no different from those associated with fires in general. Since such burns, due to contact with fire, flame, hot water, hot metal, etc., are a fairly common experience they need not be considered further here.

7.18. The range of secondary burn injuries will correspond approximately to the distance to which fires have spread. In a built-up area this will be about the same as that for mechanical destruction, referred to in paragraph 7.12. The nearer the center of the explosion, the greater will be the proportion of severe burns among persons who survive.

Primary Burns or Flash Burns

7.19. Flash burns are likely to be encountered on a large scale as the result of an atomic explosion in the air or on the surface, and so a brief description will be given of some of their characteristics. It was stated in chapter 2 that about one-third of the energy of fission appears as thermal radiation or radiant heat. Most of this enormous amount of radiation is emitted during the first second after the explosion. The high temperatures of the skin produced by this radiation result in burns of exposed personnel. These are called primary burns or *flash burns*, as they are the direct result of the flash of thermal radiation from the ball of fire.

7.20. The primary burns are generally superficial, except at close ranges. Since the radiation travels in straight lines, it burns primarily on the side facing the explosion and also produces shadow effects, like sunlight. For this reason, the primary burns have sometimes been called "profile burns."

7.21. A person in the shadow of a building would probably escape this type of injury. If standing behind a telephone-pole or a tree, those portions of his body directly shielded from the point of burst would not be burned. Likewise, his hands would not be affected if they were shielded by his body.

7.22. Clothing of the right kind can provide considerable, even complete, protection from thermal radiation injury. Heavy clothing is better than thin material, and light colors are better than dark. Light colored materials reflect more of the thermal radiation, but dark colored clothes tend to absorb it. The latter are thus more likely to scorch and cause burns on the underlying skin, especially where they fit tightly. Loose garments are desirable because they leave an insulating air space between the material and the skin. It may be noted that ordinary combat issue uniforms will protect personnel from the thermal radiation as close as 1,500 yards from ground zero in the air burst of a nominal atomic bomb (see table 6.27).

7.23. The primary burns from an atomic explosion probably are not significantly different in character from flash burns encountered in industry, as well as in other forms of warfare. Unless complicated by other factors, such as anemia or infection, flash burns heal as well as other similar burns.

7.24. The amounts of thermal radiation energy from an atomic explosion which will produce various depths of skin burn are as follows: first degree burn, 2–3 calories per sq. cm.; second degree burn, 3–4 calories per sq. cm.; and third degree burn, 8–10 calories per sq. cm. From these data, together with figure 3.41, it is possible to estimate the approximate limiting distances from ground zero at which flash burns of different degrees would be experienced, as a result of the air burst of a nominal atomic bomb at 2,000 feet. The values so obtained, for an average clear day, are given in table 7.24. The casualties to be expected from thermal radiation, with different states of the atmosphere, for men in the open and for those in foxholes, are indicated in figure 7.24, at various distances from ground zero. The corresponding distance for bombs of other energy releases may be calculated by the method described in paragraph 3.43 (see also, fig. 3.44).

---

[1] Keloids may follow any burn, even one caused by a hot stove, and, contrary to some of the reports on the Japanese cases, they are not a peculiar characteristic of atomic burns.

Table 7.24. Limiting Ranges from Ground Zero for Flash Burns from Nominal Atomic Bomb

Depth of burn	Heat energy required (cal./sq. cm.)	Approximate distance (yards)
First degree	2–3	3,500
Second degree	3–4	3,000
Third degree	8–10	2,100

Flash Blindness

7.25. Temporary blindness resulting from the intense flash of light from an atomic bomb may occur. There may be temporary exhaustion of the material in the eye, called visual purple, which makes vision possible. Blindness may then persist for some time, but usually not more than half an hour.

INJURIES DUE TO NUCLEAR RADIATIONS

Internal and External Radiation

7.26. As already mentioned, nuclear radiation effects represent the only novel type of injury accompanying an atomic explosion. Although not the most important in producing casualties, the subject will be treated in some detail here because of its general unfamiliarity. Actually, injury and sickness caused by radiations, resulting from accidental overexposure to X-rays or to the entry of radioactive materials into the body, have been known for some time. The harmful effects of nuclear radiations are, however, a new aspect of warfare introduced by the atomic bomb and by the possible use of RW agents (ch. 5). This chapter deals only with the *effects* of nuclear radiations; the problems of protection of personnel from these radiations and control of radiation dosages under both peacetime and wartime conditions are discussed in chapter 10.

7.27. Nuclear radiations may consist of alpha or beta particles, gamma rays, or neutrons. In a general way, their effects on tissues are similar. It is convenient, however, to distinguish between the ways in which the radiations are delivered to the body.

7.28. *External radiation* is that which reaches the body from outside. Gamma rays, from the immediate nuclear radiation and from radioactive contamination, are the main hazard of the external radiation. Strictly speaking, neutrons liberated during fission should also be included, but as their injurious effects do not extend as far from the point of the explosion as do the gamma rays emitted at the same time, they are of minor consequence. It is possible that in certain special cases neutrons might be significant.

7.29. *Internal radiation* is the result of radioactive material such as fission products, plutonium or RW agents, actually entering the body. Operationally this is unlikely and would be possible only in the event of a contaminating burst or an RW attack.

Effects of External Nuclear Radiation—Acute Dosage

7.30. In considering the injurious effects of external (gamma) radiation on the body, it is necessary to distinguish between an *acute exposure*, that is, an exposure of short duration, and a *chronic exposure*, which extends over a considerable time. The discussion of the effects of nuclear radiation in the present section deals with those of acute exposure such as would be due to the immediate nuclear (gamma) radiation emitted at the time of the explosion from the ball of fire and the atomic cloud, in an air burst, or it might be received from the base surge, during transit, following a subsurface burst.

7.31. The most important consequence of acute radiation exposure is what is known as "radiation sickness." It is the result of receiving a large dose of penetrating nuclear radiation over a *large area of the body* in a short time. Under these conditions, the symptoms and severity of the disease depend on the actual dosage, as indicated in table 7.31. For simplicity, persons receiving radiation dosages between 150 and 650 roentgens are considered in three groups. Actually, there is no sharp line of demarcation between the groups, and there will be some variations within each group.

7.32. The most obvious consequence of acute radiation exposure, as far as military personnel are concerned, is vomiting. In general, it may be assumed that those who do not vomit on the first day have not received a serious dose of radiation.

7.33. It may be noted that for high radiation dosages, 600 roentgens or more, symptoms first appear within 1 or 2 hours, but there may or may not be a "latent" period, lasting up to several days. During the latent period there is no apparent illness. The symptoms gradually reappear in a more serious form, and death ensues in about 2 weeks. For very large

THERMAL (HEAT) RADIATION EFFECTS

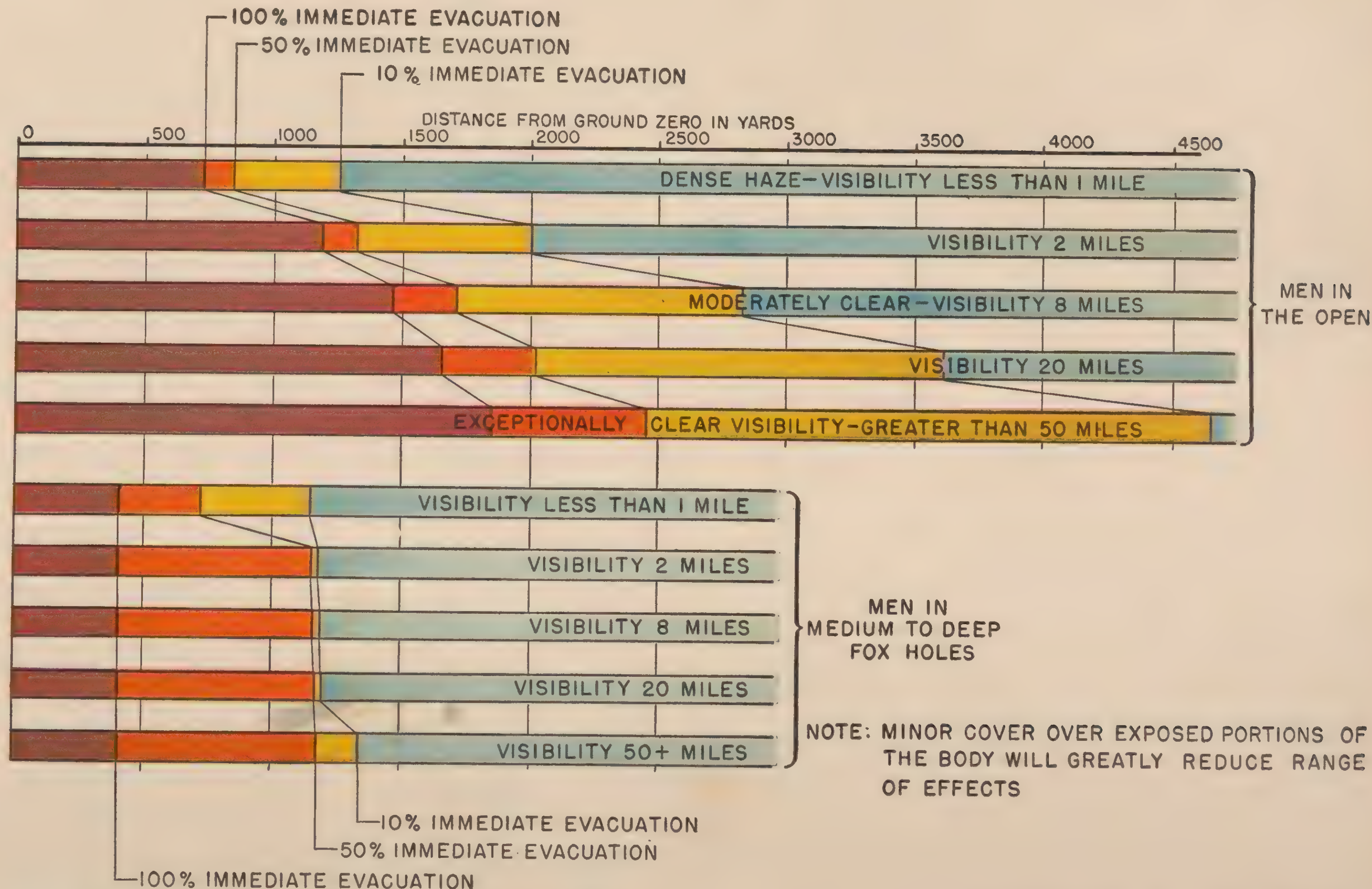


Figure 7.24. Expected casualties due to thermal radiation at various distances from ground zero due to air burst of a nominal atomic bomb at an altitude of 2,000 feet. The influence of the state of the atmosphere and of shelter in foxholes is shown. (For similar chart showing effects of nuclear radiation, see fig. 7.40.)

Table 7.31. Symptoms of Radiation Sickness

Time after exposure	500–650 roentgens	300–500 roentgens	150–300 roentgens
	Nausea and vomiting on first day.	Nausea and vomiting on first day.	Nausea and vomiting on first day.
First week	No definite symptoms.	No definite symptoms.	No definite symptoms.
Second week	Diarrhea. Vomiting. Inflammation of mouth and throat. Fever. Rapid loss of weight. Death (mortality about 95 per cent).	Beginning hair loss. Loss of appetite and general sick feeling.	
Third week		Fever. Severe inflammation of mouth and throat.	Hair loss. Loss of appetite and general sick feeling.
Fourth week		Pallor. Skin hemorrhages. Diarrhea and nose bleeds. Rapid loss of weight. Death (mortality about 50 per cent at 450 roentgens).	Sore throat. Pallor. Skin hemorrhages. Diarrhea. Moderate loss of weight. (Recovery likely unless complicated by poor previous health or superimposed injuries or infections.)

radiation dosages, of 1,000 roentgens or more, there may be no latent period. The individual is then an immediate and persistent casualty. In general, the larger the dosage, the shorter is the latent period.

7.34. The occurrence of the latent period is significant from a military standpoint, because it means that a person exposed to the immediate nuclear radiation may apparently not be incapacitated. Even with as large a dose as 300 roentgens, he will still be capable of physical activity for a few days, if the urgency is sufficiently great.

7.35. Recovery from the illness due to exposure to a large acute dose of nuclear radiation will leave the individual apparently normal. However, although the person will appear and feel well, further exposure after recovery from severe radiation sickness is undesirable if it can be avoided.

7.36. Exposure of essentially the whole body to radiation would result in the symptoms described in table 7.31. If part of the body is adequately protected, a given dosage usually has a less serious effect. The situation here is somewhat similar to that referred to in connection with burns. In considering the effects of nuclear radiation, the total dosage received, the dose rate and the volume of body tissue exposed are important.

7.37. It is not only the volume of the body, but also the particular area or organs exposed that is significant. This is because some parts of the body are much less sensitive to nuclear radiation than others. A large dose received on the arms or legs, for example, might produce only local effects, while the same dose on the abdomen might be fatal. If the entire body is exposed to the radiation a dose of at least 600 roentgens will prove lethal in most cases. If the abdomen only is irradiated, it has been estimated that about 800 roentgens is lethal. However, if the abdomen is protected, and the rest of the body is exposed, something like 1,400 roentgens probably would be required. It may be mentioned that in the X-ray treatment of cancer, thousands of roentgens frequently are received by a small volume of tissue without death or serious illness resulting.

7.38. There is a possibility that for psychological or other reasons an individual may develop symptoms, such as nausea and vomiting, which simulate those of radiation sickness, but are actually not due to radiation exposure. The decision between real and apparent radiation sickness however can be made by medical personnel within 24 hours.

7.39. It cannot be emphasized too strongly that radiation sickness is not a communicable disease, nor does the sickness cause the patient to be radioactive.

A person suffering from radiation sickness can be handled with complete safety.

Acquisition and Effects of Acute Radiation Dosages

7.40. The limiting distances from ground zero at which various acute dosages of the immediate nuclear radiation would be received by unprotected personnel can be derived from figure 3.51. This applies to the air burst of a nominal atomic bomb, at the height of 2,000 feet. The results are given in table 7.40 together with the probable effects on personnel receiving the radiation over the whole body. They are also represented in figure 7.40, where the benefits of various types of protection are indicated. The corresponding distances for bombs of other energies can be derived from figure 3.55.

Table 7.40. Probable Effects of Acute Nuclear Radiation over Whole Body

Range from air burst ground zero (yards)	Acute dose (roentgens)	Probable effects
1,750	50 or less	No symptoms of sickness. No decrease in combat effectiveness.
1,570	100	Nausea and vomiting for about 1 day in approximately 2 percent of personnel. None need evacuation; all able to perform duty.
1,450	150	Nausea and vomiting for about 1 day in approximately 25 percent of personnel. No personnel evacuation expected.
1,400	200	Nausea and vomiting for about 1 day in approximately 50 percent of personnel. Evacuation of about 25 percent at end of 1 week. All need to be evacuated as soon as possible. No deaths anticipated.
1,350	300	Nausea and vomiting in all peronnel on first day. All need to be evacuated immediately. About 25 percent deaths anticipated, but will be reduced by adequate medical treatment. Survivors ineffective for full military duty about 3 months.
1,250	450	Nausea and vomiting in all personnel on first day. All need to be evacuated as soon as possible. About 50 percent deaths anticipated, but will be reduced by medical treatment. Survivors ineffective for full military duty about 6 months.
1,150	650	Nausea and vomiting in all personnel within 4 hours. Evacuation of all on first day. Up to 100 percent deaths may be anticipated. Any survivors ineffective for full military duty for over 6 months.

7.41. An acute radiation dosage might be received from the base surge during transit, following an underwater, an underground, or a surface burst. An individual who is exposed during the whole period in which the base surge is passing, will not only receive the transit dose of radiation, as represented in figure 4.29, but, in addition, he will be exposed to the deposited contamination, from base surge and fall-out, at the time when the radioactivity is very high. If there were no surface wind, an acute dose of 600 roentgens of nuclear radiation would be received in 4 or 5 minutes, at distances up to 2,500 yards from surface zero in the explosion of a nominal atomic bomb. At 2,700 yards, the dose would be approximately 450 roentgens, while at 3,000 yards, it would be down to 100 roentgens. The probable effects on personnel would be as indicated for the same doses in table 7.40.

7.42. The distances just given are intended only as a rough guide, since they are based on the supposition that there is no wind. A surface wind, even one of low velocity, such as the 5-knot wind experienced at Bikini, will markedly increase the various distances in the downwind direction, and decrease them correspondingly upwind. For example, at Test Baker, the range for 100 roentgens was about 4,500 yards or more downwind, but only about 2,000 yards upwind. The crosswind distances were approximately those given in the preceding paragraph.

Dosages in Aircraft

7.43. In the event that an airplane were to fly through the atomic cloud, the crew of the aircraft would receive an acute dose of radiation. The severity of the dose, of course, would depend upon the speed of the plane and the time after detonation. In general, even with high speed planes, the crews might receive lethal doses if the passage through the cloud is made during the first 10 minutes.

7.44. In addition to the acute dosage of radiation received directly from the cloud, the dosage that might be received from radioactive contamination deposited on the exterior of the aircraft, within the engine, or in the interior of the plane, should be con-

NUCLEAR (GAMMA) RADIATION EFFECTS

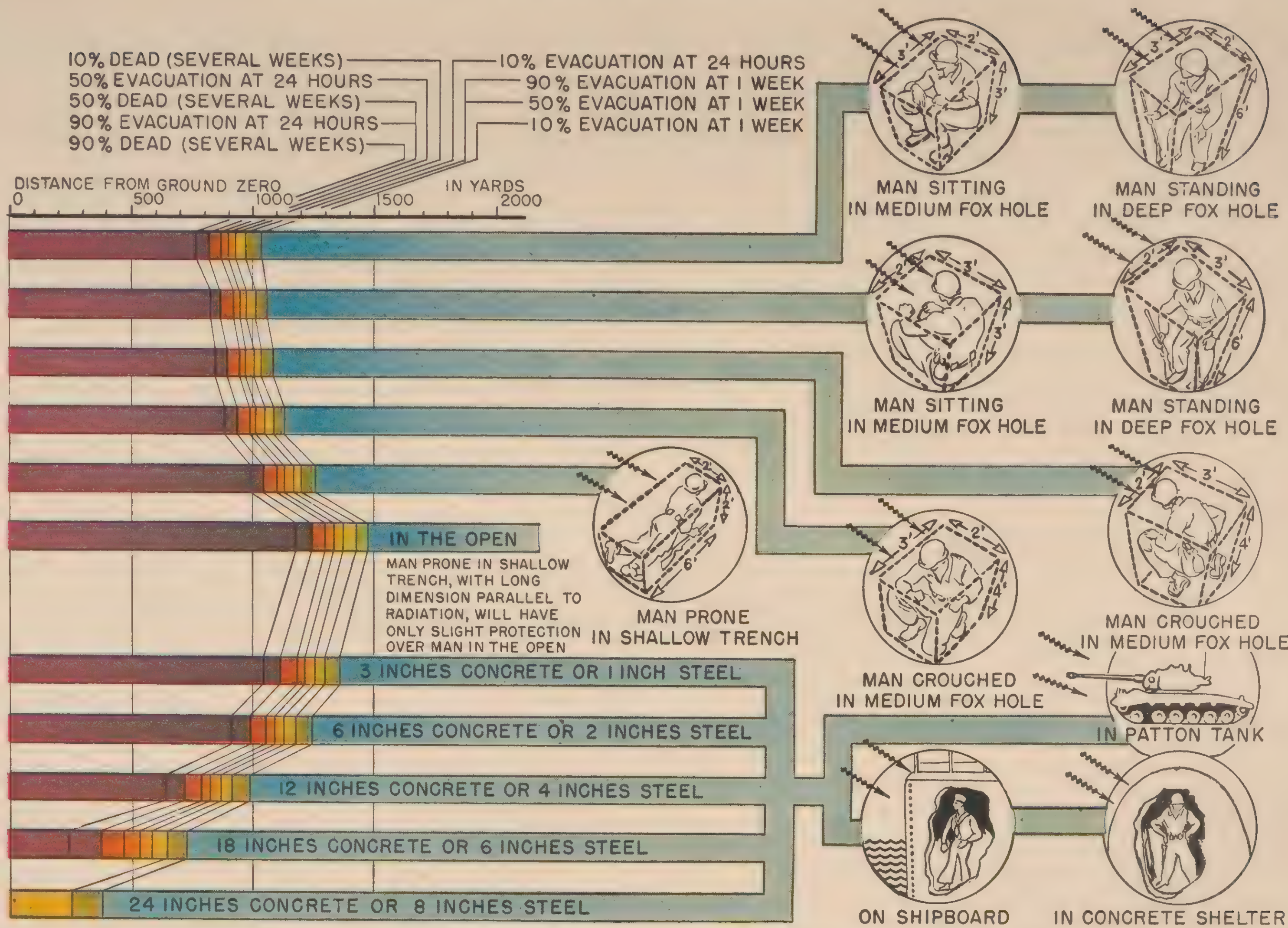


Figure 7.40. Expected casualties due to initial nuclear radiation at various distances from ground zero due to air burst of a nominal atomic bomb at an altitude of 2,000 feet. The influence of various types of shelter is shown. In the case of personnel "in the open," it should be noted that the above casualty ranges would apply only for personnel completely shielded from the thermal radiation (for example, by heavy clothing) since the ranges for possible thermal injury considerably exceed those for nuclear radiation injury. (For similar chart showing effects of thermal radiation, see fig. 7.24.)

sidered. This will probably not contribute significantly to the total radiation received by the crew but may be both an external and internal hazard to maintenance crews involved in major repair work.

Chronic Dosage—Residual Radioactivity

7.45. The preceding discussion has applied to the consequences of acute doses of nuclear radiation, i.e., those received in a short time. If the same total dose of gamma radiation is received over a long period, i.e., as a chronic dose (par. 7.30), the effects may be less serious. In other words, the dose rate, i.e., the rate at which the radiation is received by the body, is an essential factor in determining the harm that may be done. This matter is important in connection with exposure to RW agents or to the residual radioactivity from fission products following an atomic explosion of the contaminating type, such as a subsurface or surface burst. In cases of this kind, the dose rate might be low, but as a result of continuous exposure, the total dosage would be high.

7.46. If the chronic dose rate is not too high, partial recovery can begin even while the body is exposed to nuclear radiation. A delay of about 12 hours occurs, this being apparently the time required for appreciable recovery while irradiation proceeds. For exposures of less than 12 hours the total dosage received, and not the dose rate, determines the seriousness of the injury. For longer exposure times, there is a certain degree of recovery during the period of exposure, and a larger total dose is necessary to produce a given effect.

7.47. The receipt of 200 roentgens of nuclear radiation in a short time would result in vomiting and nausea in about 50 percent of the exposed personnel, and these individuals would become combat ineffectives. On the other hand, a series of eight exposures of 25 roentgens each at weekly (or longer) intervals, would be expected to have no effect on combat ability. This fact might be important in such cases as the occupation of a contaminated area by ground forces, or the performance of missions by combat crews in a contaminated aircraft.

7.48. The probable effects of a series of chronic exposures upon successive days are indicated in table 7.48 in terms of the equivalent acute dose. Thus a total of 480 roentgens spread over 32 days is expected to have roughly the same effect as 360 roentgens over 6 days or an acute dose of less than 200 roentgens.

Table 7.48. Probable Effects of Chronic Whole Body Gamma Radiation Doses

Daily chronic dose	Days exposure	Actual total dose	Acute dose equivalent (less than)
60 r	6	360 r	200 r
30 r	5	150 r	100 r
30 r	14	420 r	200 r
15 r	12	180 r	100 r
15 r	32	480 r	200 r

External Beta and Alpha Particles

7.49. Fission products and probably all substances likely to be used as RW agents emit beta particles, as well as gamma rays. If they have sufficient energy, such particles may penetrate to a depth of one-half inch of body tissue. Consequently, if there is continued exposure to the residual radioactivity, beta particles may, in some circumstances, constitute an additional external radiation hazard. Although they are very unlikely to produce radiation sickness, beta particles can augment the damage caused by the more penetrating gamma rays and thus intensify the illness. The relative importance of external beta exposure is increased when physically handling heavily contaminated objects or equipment.

7.50. Since beta particles themselves, from an external source, will not penetrate appreciably into the body, primary damage will be restricted to the skin. Continuous contact with a beta particle emitter, such as might result from sleeping in a highly contaminated place or from handling considerable amounts of active material, will cause reddening and blistering of skin. The dosage required for immediate damage is very high, probably on the order of thousands of roentgen equivalents.

7.51. It is unlikely that any situation would arise after an atomic explosion or an RW attack in which beta particles are not associated with gamma rays. Because of the greater penetrating power of the latter, it is evident that steps, such as shielding, taken to decrease the external gamma radiation will automatically decrease, or eliminate, the external hazard from beta particles.

7.52. Alpha particles are stopped by an inch or two of air and are unable to penetrate beyond the outer layers of unbroken skin. As a result, they do not constitute a danger as far as external radiation is concerned.

Internal Nuclear Radiation Hazard

7.53. The internal radiation hazard arises from the localization of radioactive matter within the body. Certain elements, such as plutonium or strontium, are deposited in the bones; the radiations then affect the blood-forming tissues and there is a reduction in the numbers of both white and red blood cells. Alpha particles are especially potent in this respect for, in spite of its smaller penetrating power, an alpha particle can do ten to twenty times as much damage inside the body as a beta particle of the same energy.

7.54. The effects of internal radiation usually do not become apparent for some time, perhaps years. There is at first a long period during which no symptoms appear. After a number of years some may die of anemia and secondary infections. In some cases, cancer may result.

7.55. Radioactive substances can gain entry into the body through the mouth and the digestive system, through the lungs as a result of inhaling contaminated dust particles, or through cuts or wounds. Quite small quantities of certain active materials, when fixed in the body, can do considerable harm and so, when radioactive contamination is encountered, care must be taken to prevent its entry into the system, especially by inhalation.

7.56. Internal radiation hazards in military operations do not exist after an airburst. Internal hazards following a contaminating explosion may be avoided if ordinary precautions are taken. Furthermore, a person receiving significant internal radiation during the transit of a base surge would simultaneously receive a lethal dosage of external radiation. Only under unusual circumstances will there be an internal hazard from residual contamination.

7.57. Beta particles may also constitute an internal hazard especially if emitted by certain radioactive isotopes of long half life, such as those of strontium and yttrium, which tend to become fixed in the bone. During the first few months after a detonation the beta emitters among the fission products are liable to be of greater hazard than plutonium, while after a year or more plutonium may be more dangerous.

7.58. During the first few hours, or a few days, after a contaminating atomic burst, persons close enough to ground zero to take into the body a significant amount of radioactive material would undoubtedly receive a lethal dose of residual external radiation. Most of the penetrating nuclear radiation is emitted by isotopes with short half lives, and the external hazard is largely dependent on these isotopes. Thus, it is apparent that these short-lived isotopes and the danger due to the residual external radiation will disappear together. The radioactive materials of long half lives then remain to constitute the main source of the lingering internal radiation hazard.

Additional Effects of Radiation

7.59. There are a number of effects of radiation, in addition to those considered above, which have attracted popular interest. For this reason, and because there is much misunderstanding concerning them, they will be considered briefly here, although their importance is actually relatively small.

Cancer

7.60. The best known example of cancer due to radiation is the increased incidence of leukemia or "cancer of the blood" among radiologists who are exposed to small doses of external radiation over many years. Continual internal radiation may induce cancer of the bone in some instances. However, as already seen, internal radiation from an atomic explosion is a minor hazard if reasonable precautions are taken.

Cataracts

7.61. Cataracts of the eyes have been observed in persons subjected to very high doses of radiation. They generally make their appearance after a latent period of several years. Only those who were sufficiently near ground zero to receive a large dose of radiation, and have also escaped the other lethal effects of the atomic bomb, are likely to develop cataracts. Survival in these cases will have been due to an accidental combination of circumstances, so that the victims will, in fact, be fortunate to have escaped with their lives.

Loss of Hair

7.62. Loss of hair will occur among people receiving 200 roentgens or more of immediate gamma radiation (see table 7.31). However, in the course of a few months, growth will usually commence again, even in severe cases of hair loss. There was no evidence of permanent loss of hair among the survivors after the atomic explosions over Japan.

Sterility

7.63. While sterility has been publicized as a serious after effect of radiation exposure, it should be pointed out that the dose required to cause permanent sterility approaches the lethal dose. Hence, few persons who might be permanently sterilized would survive an atomic explosion. Further, those who suffer a sterilizing, but not lethal, dose of gamma radiation are apt to succumb to indirect blast effects or to burns. For these reasons, permanent sterility among survivors of an atomic attack will be rare. These considerations apply to both men and women. There will be miscarriages in women receiving large doses of radiation, but if pregnancy is completed the offspring will in all probability be normal.

Impotency

7.64. After the atomic explosions at Hiroshima and Nagasaki, a few persons complained of impotency. This is quite distinct from, and not a consequence of, sterility. Impotency refers to the inability to perform sexual intercourse, while sterility is the inability to have offspring. Thus, a man may be sterile but not impotent. There is no evidence that impotency is a direct result of radiation exposure, and such cases as were reported presumably were due to the unusual psychological stress of the situation.

Genetic Changes

7.65. The genetic effects, that is, hereditary effects, of nuclear radiation are well known and have been studied for many years with small animals and other lower forms of life. As far as human beings are concerned, there is little probability of abnormal offspring, at least for the next few generations, due to radiation from atomic explosions.

TREATMENT OF INJURIES

Combined Effects of Injuries

7.66. In an atomic explosion, especially in an air burst, the areas in which blast injuries, burns, and immediate radiation effects occur will overlap one another. Hence, it will be relatively uncommon to find a victim suffering from only one type of injury. More frequently two or more kinds of injury will be combined to produce additional complications. Two cases of such additive effects may be referred to as being especially important.

7.67. The first is that of combined blast effects and burns. Individuals who have sustained slight or no blast injury may be trapped in buildings shattered by the blast, and so be severely burned. Another possibility is that flaming debris may fall on escaping persons. A different type of combined blast and burn effect is that in which mechanical wounds complicate and make difficult the treatment of burns.

7.68. The second case involves a fairly high nuclear radiation dosage combined with blast injuries or burns. The damage to the body caused by radiation may delay the healing of both wounds and burns, and increases the possibilities of complications.

Therapy and First Aid

7.69. It is certain that if personnel were exposed to an atomic detonation, medical care and evacuation would save many more lives than were saved in Japan. It is pointed out that the Japanese had almost no medical treatment, and no evacuation. During World War II and since, a great deal of progress has been made in the treatment and handling of casualties. Among the improvements are the following: earlier first aid reaches the patient after injury; blood, plasma, and drugs for the patient in shock or who has bled; more efficient drugs to combat infection; evacuation to a rear area for early treatment to specialized types of injuries; stockpiling of medical supplies and equipment in target areas. These improvements may reduce expected fatalities far below the estimates that are currently given.

7.70. Due to the probability of tremendous numbers of casualties, each individual should know how he can help himself and others. An injured person

need not remain unaided until a corpsman or a doctor can reach him. This should be emphasized to military personnel when receiving instruction in elementary first aid. It will have the dual effect of teaching each person what he can do for himself when he receives an injury and also what he can do for his neighbor.

7.71. In conclusion, it may be said that the conventional treatments for mechanical injuries and burn casualties, such as are rendered to casualties in any military operation, will be used following an atomic attack. No immediate therapy need be given for radiation sickness. Later treatment of casualties will consist of prevention of secondary infection and re-establishment of the function of the blood-forming organs. This usually can be accomplished by insuring that the victim is given physical rest, good nursing care, antibiotic drugs, and plasma and blood transfusions.

SUMMARY

Casualties from an atomic explosion will be due to—(1) blast and shock; (2) burns; (3) nuclear radiation. Primary blast injuries, due to direct action of air blast, will be rare. Mechanical injuries, caused by collapsing buildings, missiles, etc., are a secondary result of blast and shock. Such injuries will be experienced in atomic explosions of all types.

Primary (or flash) burns are a direct result of thermal radiation from the bomb, while secondary burns are caused by fires subsequent to the explosion. Flash burns will be common after an air burst, but they will be negligible after subsurface bursts because the thermal radiation is absorbed by water or earth. In an air burst burns may occur as far as 2 miles from ground zero.

Radiation injury may be due to external radiation, reaching the body from outside, or to internal radiation, resulting from radioactive material taken into the body. A dose of external radiation can be received in a short time (acute) or over an extended period (chronic). An acute dose can be due to nuclear radiation emitted from the bomb in an air burst, or from the base surge in a subsurface burst. A chronic dose can be received from the residual or lingering radiations from contaminated surroundings.

The first symptoms of radiation sickness are nausea and vomiting. This may be followed by a latent period, after which further symptoms appear. An acute dose of 650 roentgens or more, over the whole body, will prove fatal to nearly all exposed individuals; about 50 percent of those receiving 450 roentgens will die; and most of those receiving 200 roentgens will become sick, but nearly all should recover. A chronic dose, spread over a considerable time, is less harmful than an acute dose of the same quantity of radiation.

Residual radiation may be either an external or an internal hazard. The *external* hazard from gamma radiation is important, but that due to beta and alpha particles is not significant. On the other hand, both beta and alpha emitters can, under unusual circumstances, represent a long-term *internal* hazard if they enter the body.

Chapter 8

RECOGNITION OF RADIATION HAZARDS

INTRODUCTION

Radiological Defense in the Military Organization

8.01. It has been seen in the preceding chapters that the damage caused by the explosion of an atomic bomb is due to blast and shock, heat and fire, and nuclear radiation, both immediate and residual. Although they are on a much larger scale, the effects of blast and fire are similar to those from conventional HE and incendiary bombs. It is, consequently unnecessary to give detailed consideration to defensive measures against these effects in this manual, since they are no different, except in their greater magnitude, from those with which military personnel are already familiar. Nuclear radiation, however, represents a new source of casualties in warfare, and radiological defense is thus a command responsibility, just as is the control of blast and fire damage.

8.02. It should be emphasized that the effects of nuclear radiation are not usually the most important aspects of an atomic explosion. The atomic bomb, as stated earlier, is primarily a blast weapon. Nevertheless, radiological defense introduces some new problems into the military organization and it is essential that they should be clearly understood.

8.03. While it might be necessary to assign radiation specialists to some major military commands, it should be noted that most commands already have a large part of the organization necessary for atomic warfare defense (see ch. 13), including defense against its radiological hazards. They are equipped with transportation, communication, and many other facilities needed to meet emergency situations, and radiation is another such situation introduced by atomic weapons. In many respects, too, defense against the residual contamination is similar to defense against chemical agents—the elements of detection, hazard evaluation, and decontamination are common to both. The existing organization for defense against chemical attack is thus being extended to include radiological defense.

RECOGNITION OF THE HAZARD

Preliminary Observations

8.04. The first step in defense against nuclear radiation is *to recognize the existence of the hazard and to assess its importance.* Radiation cannot be seen or felt; in fact, it cannot be detected by any of the five natural senses. Its detection requires the use of special instruments and devices which are described below. Nevertheless, preliminary deductions concerning the possible or probable existence of a radiation hazard can be made from general observations. It is essential that such observations should be made and reported to a designated control center.

8.05. An atomic air burst, as already explained, is noncontaminating, except to aircraft flying through the atomic cloud. Consequently, if the evidence points to a burst of this type, it should not be necessary for the whole of the radiological defense organization to go into action. The characteristics of an atomic explosion in the air are the appearance of an intense flash of light, lasting up to 3 seconds, the rising ball of fire, and usually the development of the mushroom-shaped cloud, reaching a height of as much as 30,000 feet or more in a few minutes. For a true, noncontaminating air burst, no great amount of dirt or other debris will be sucked up, and the cloud stem will have a light yellowish color.

8.06. An intense flash of light and a visible ball of fire, with a mushroom-shaped cloud having a dark stem, may point to a surface burst. Such an explosion will be accompanied by a cloud of dirt and dust (see fig. 4.71) and possibly a base surge. A radiation hazard is then to be expected in the vicinity of ground zero immediately after the explosion. Later some radioactive contamination, depending on the wind and weather conditions, may be found further away.

8.07. In an underground explosion, the flash of light from the ball of fire might be visible for a very short time as the latter breaks through the earth's surface; on the other hand, the light might not be seen at all. The chief indication of an underground burst would then be a definite earth shock accompanied by a tremendous shower of earth and other debris, and the formation of a dirt cloud and base surge (see fig. 4.48). It is quite probable that detonations of other types, not involving atomic weapons, might be mistaken for underground atomic explosions. But, in view of the great radiological hazard associated

with an underground burst, it will not be safe to ignore any reports which indicate the possibility that an atomic bomb has been detonated under these conditions. The hazard will be greatest in the crater region and will probably extend some distance around it, particularly in the downwind direction.

8.08. An underwater atomic burst can produce radiation hazards both at sea and on adjoining land areas. Such an explosion may be accompanied by a huge column of water topped by a cauliflower-shaped cloud, the maximum height attained being some 8,000 feet. Due to the base surge, contamination will be considerable, especially in the downwind direction. In the event of a very deep underwater atomic explosion, there might be no water column and no base surge. Essentially all the radioactive residue from the bomb would then remain in the water.

8.09. The composite photographs in figure 8.09 are presented as a partial help in the identification of different types of bursts. They show an air burst, a surface burst, and an underwater burst on the same dimensional scale. An underground explosion may be expected to be somewhat similar to an underwater burst, except that the tremendous quantity of dirt raised will cause the cloud to be dark colored. The most noticeable difference to a moderately distant observer between an air burst and a surface burst, on the one hand, and a subsurface burst on the other hand, is that in the latter case, the height attained by the cloud is considerably less and the base is much broader, lacking the stem or chimney effect characteristic of an air burst.

8.10. Attention should be drawn to the similarity of the photographs depicting the air and surface bursts. It is evident that, in some cases at least, it may not be possible for observers to distinguish between them at a distance. This means that even if it is believed that an atomic explosion has been a high air burst, there is a possibility of error; consequently, the residual radiation hazard must not be ignored.

8.11. From the information transmitted through the usual communication channels, shortly after an atomic attack, a commander might be in a position to estimate roughly the locations in which radiological hazards may exist. He could then decide on the most appropriate steps to be taken that would be consistent with his primary mission. After a reported air burst, the first recovery effort would be to deal with the effects of blast and fire. A check to confirm the absence of radioactive contamination should be made as soon as practicable. In the event of a surface or subsurface explosion, the whole radiological defense organization would be put into action.

Radiation Detection Instruments

8.12. If the general evidence points to the existence of an appreciable radiation hazard in certain locations, the next step would be to confirm the presence of the hazard and to evaluate its magnitude. For this purpose, special devices for the detection of nuclear radiation are available; these are generally referred to as *radiac instruments*, or simply as *radiacs*. Actually many such devices have been developed,[1] but it seems probable that essentially all the needs can be met by two or three standard types. The process of measuring radiation intensities or radiation exposures is frequently called *monitoring*. The person using the detection instrument is referred to as a monitor.

8.13. Specific information of two kinds is required in order to deal with the problems resulting from nuclear radiation. First, it is necessary to determine whether a particular area, region, or piece of equipment is contaminated or not. If it is contaminated, then it is necessary to know the intensity, or dosage rate, of the radiation at various points. The dosage rate is usually expressed in roentgens per hour (see par. 3.51), or in milliroentgens per hour, where a milliroentgen is a one-thousandth part of a roentgen.

8.14. For this purpose *survey meters* (or dose-rate meters) are used. From a knowledge of the dose rate of the radiation, it is possible to determine the hazard in occupying a particular area or in using equipment. If the area is not safe for permanent occupation, the readings of the survey meter can be used to calculate how long personnel can remain with reasonable safety.

8.15. The second type of information required is the total radiation dosage, expressed in roentgens or milliroentgens, received by each individual exposed

[1]For further descriptions of radiacs, see *Radiological Defense Manual*, Volume IV.

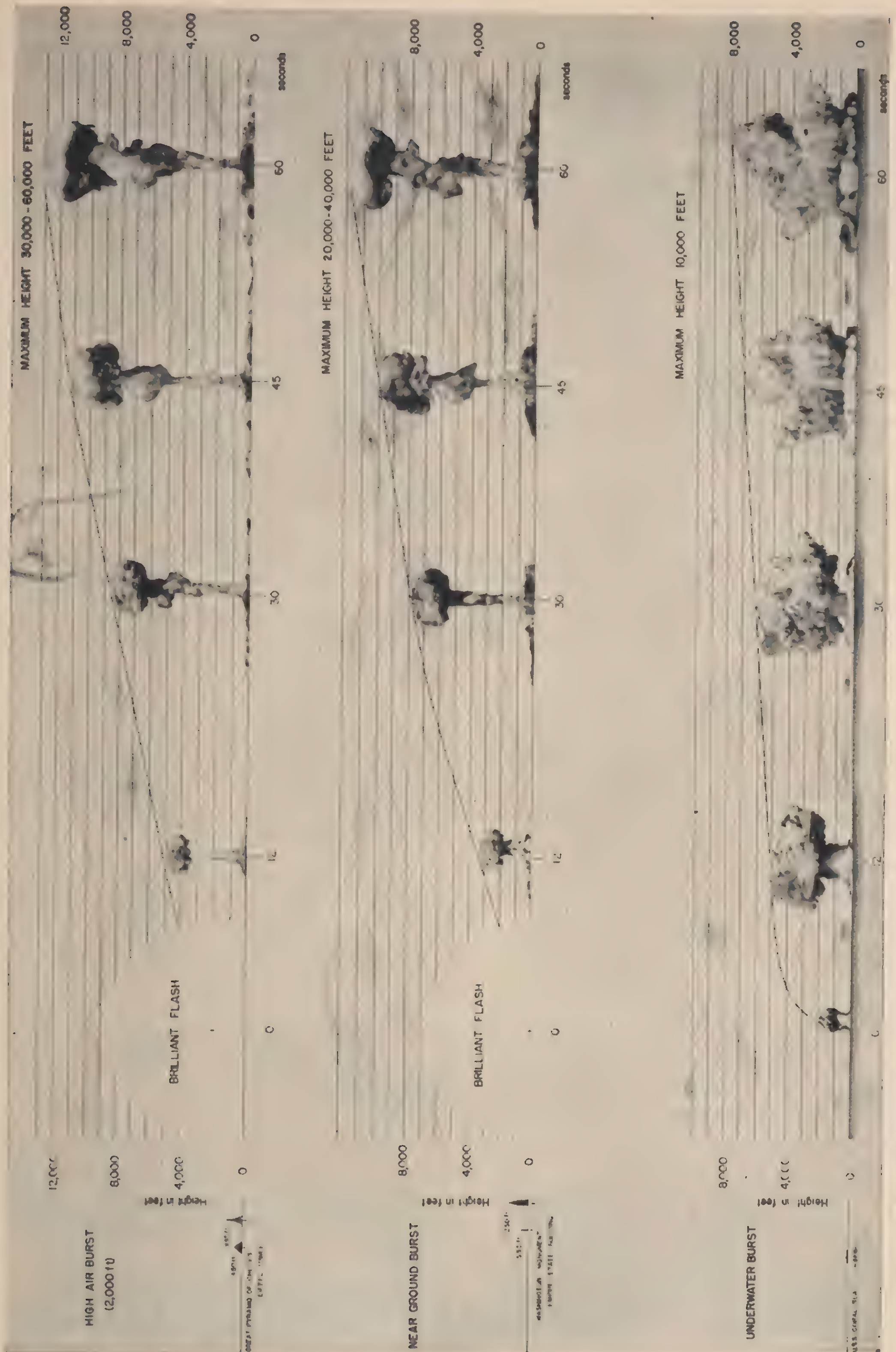


Figure 8.09. Composite photographs, on the same dimensional scale, showing development of an air burst, a surface burst, and an underwater burst.

to nuclear radiation. It will be recalled (ch. 7) that the nature and severity of radiation sickness depends on the total dose, and also upon whether it is received in a short time, say less than 12 hours, or over a long period. From a knowledge of the total exposure to radiation, a commanding officer can properly take into account the influence of this factor on the combat effectiveness of his unit. Devices which measure the total dose of nuclear radiation in roentgens (or milliroentgens) received over a period of time are called *dosimeters*.

8.16. At present there is no single instrument that will conveniently serve both as a dose-rate meter for surveying purposes and as a dosimeter for determining the exposure of personnel. Consequently, devices of different kinds are used for these two purposes. It is a fortunate circumstance that while surveying instruments, which are not required in very large numbers, are moderately complicated, dosimeters, to be worn by all personnel liable to radiation exposure, are relatively simple. Because of the differences in character, dose-rate meters and personnel dosimeters will be considered separately.[2]

SURVEY METERS

General Principles

8.17. Although several different kinds of instruments have been devised for the measurement of nuclear radiation, two are at present in general use as survey meters in radiological defense—(1) the ionization chamber (or ion chamber), and (2) the Geiger-Mueller counter (or G-M counter). Both devices are somewhat similar in the respect that they make use of what is called the ionizing property of nuclear radiation. When such radiation passes through air, or other gas, there are formed electrically charged particles called ions, positive ions and negative ions being produced in equal numbers. The rate of formation of these ions by the nuclear radiation is a measure of the intensity or dose rate of the radiation.

Ionization Chamber Instruments

8.18. In the ion-chamber type of survey meter, the chamber is usually an air-filled, plastic container, treated so that the inner walls are electrically conducting. A wire or network of wires, insulated from the container, is sealed inside. A voltage is applied between the container and the wires by means of a battery of about 100 volts. When nuclear radiation enters the chamber, it produces ions in the gas; the positive ions are then attracted to the negatively charged part (cathode), while the negative ions (or electrons) are attracted to the positively charged part (anode).

8.19. As a result, there is a flow of electric current, its strength being determined by the rate at which ions are produced in the chamber. In other words, for a particular type of nuclear radiation, the current strength is a direct measure of the radiation dose rate. This current is too small to be observed directly on instruments, but it can very easily be amplified by means of an electronic circuit using special vacuum tubes called electrometer tubes. A meter attached to the circuit can then be calibrated so as to read the dose rate directly in roentgens per hour.

8.20. Ionization chamber instruments have been made in a great variety of forms for different purposes. The portable types have been particularly useful for measuring the dose rates of gamma radiation of moderate or high intensities. More recently, instruments of wide range have been developed; they can be used to indicate dose rates from 0.5 milliroentgen per hour to 500 roentgens per hour (0.5 mr/hr. to 500 r/hr.).

8.21. The ion chamber, which is the actual radiation-detection unit, is usually built into the body of the instrument (fig. 8.21a), but if necessary it could be made in the form of a probe with a cable connection to the box containing the amplifying circuit, batteries, and meter. The latter arrangement would be useful for detecting the presence of contamination in recesses. Alternatively, the ion-chamber unit could be mounted on the exterior of a vehicle or tank, with the remainder of the instrument in the interior (fig. 8.21b). Since the crew would be partially protected from gamma radiation by the material of the vehicle or tank, it would be possible to approach and monitor a contaminated area with less exposure to personnel.

8.22. Although most ion-chamber instruments are designed to detect only gamma radiation, they can be adapted for use with beta and alpha particles. How-

[2] A dose-rate meter and a dosimeter may be compared to the two functions of an automobile speedometer. The dose-rate meter, indicating the dose-rate in roentgens per hour, is similar to the needle which registers the speed of the automobile in miles per hour. The dosimeter, on the other hand, gives the total exposure in roentgens over a period of time, and is equivalent to the mileage indicator.

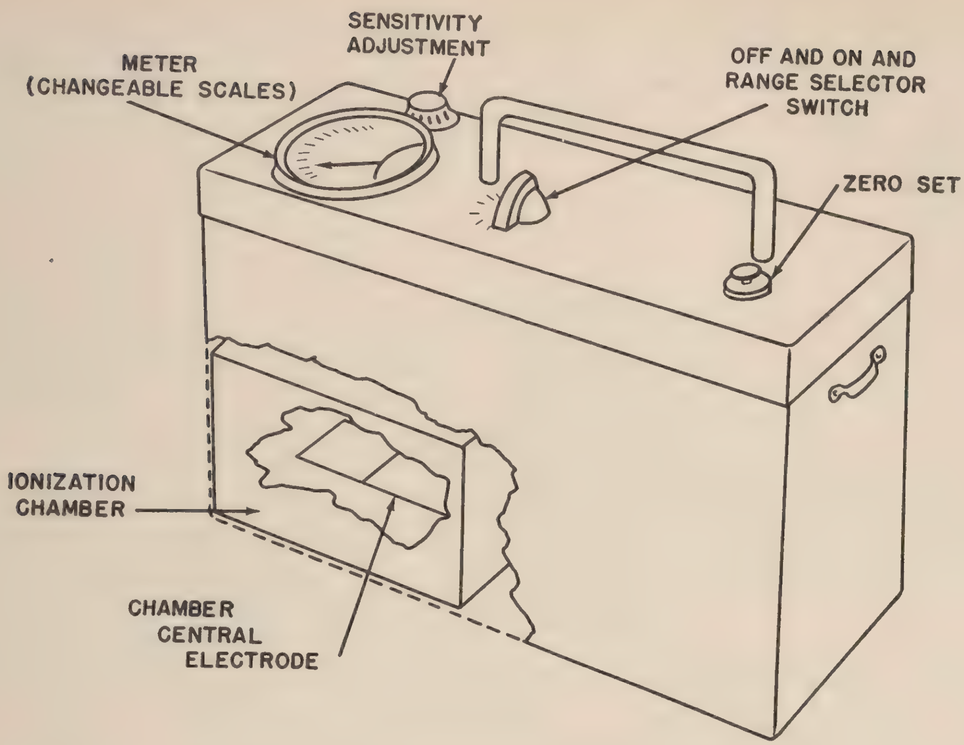


Figure 8.21a. Cutaway diagram of an ion chamber survey meter.

ever, in their present form, military ion chambers are not suitable for the measurement of alpha particles. In the instruments designed to detect both beta particles and gamma radiation, the chamber unit has a very thin "window" which will permit the passage of beta particles, as well as gamma radiation, into the ion chamber. An instrument which measures beta particles as well as gamma radiation is frequently called a beta-gamma meter.

Geiger-Mueller Counters

8.23. The detecting part of the Geiger counter is the Geiger tube (fig. 8.23). This is a cylindrical gas-filled tube having a conducting cathode coating on the interior of the tube wall and a fine metal anode wire, insulated from the cathode, running down the center of the tube. The conducting cylinder is attached to the negative pole, and the insulated central wire to the positive pole of a high-voltage source. Geiger counters require 700 to 1,000 volts instead of the 100 volts used for the ion-chamber type of instrument. When nuclear radiation enters the tube, ions are produced in the gas, as described above. The negative ions are actually very small particles, called electrons, and because of the high voltage applied between the cylinder and the central wire, the electrons move rapidly toward the wire. If the voltage is sufficiently high, the fast-moving electrons act like nuclear radiations and are able to produce more ions in the gas. The negative ions (electrons) so formed are, in turn, accelerated by the high voltage and produce more ions, and so on.

8.24. Under the proper conditions, therefore, a single pair of ions formed in the Geiger tube by nuclear radiation will result in what is called an ionization "avalanche." Such an event is equivalent to a large pulse of current through the tube and this, with little amplification, can be used to actuate a meter or other device. Instruments operating in the high-voltage region actually count these current pulses as they occur, and for this reason are called Geiger "counters." The rate at which the pulses form is a measure of the intensity of the nuclear radiation. The pulse rate can be read on a meter and when of very low intensity can be determined by the clicks in an earphone.

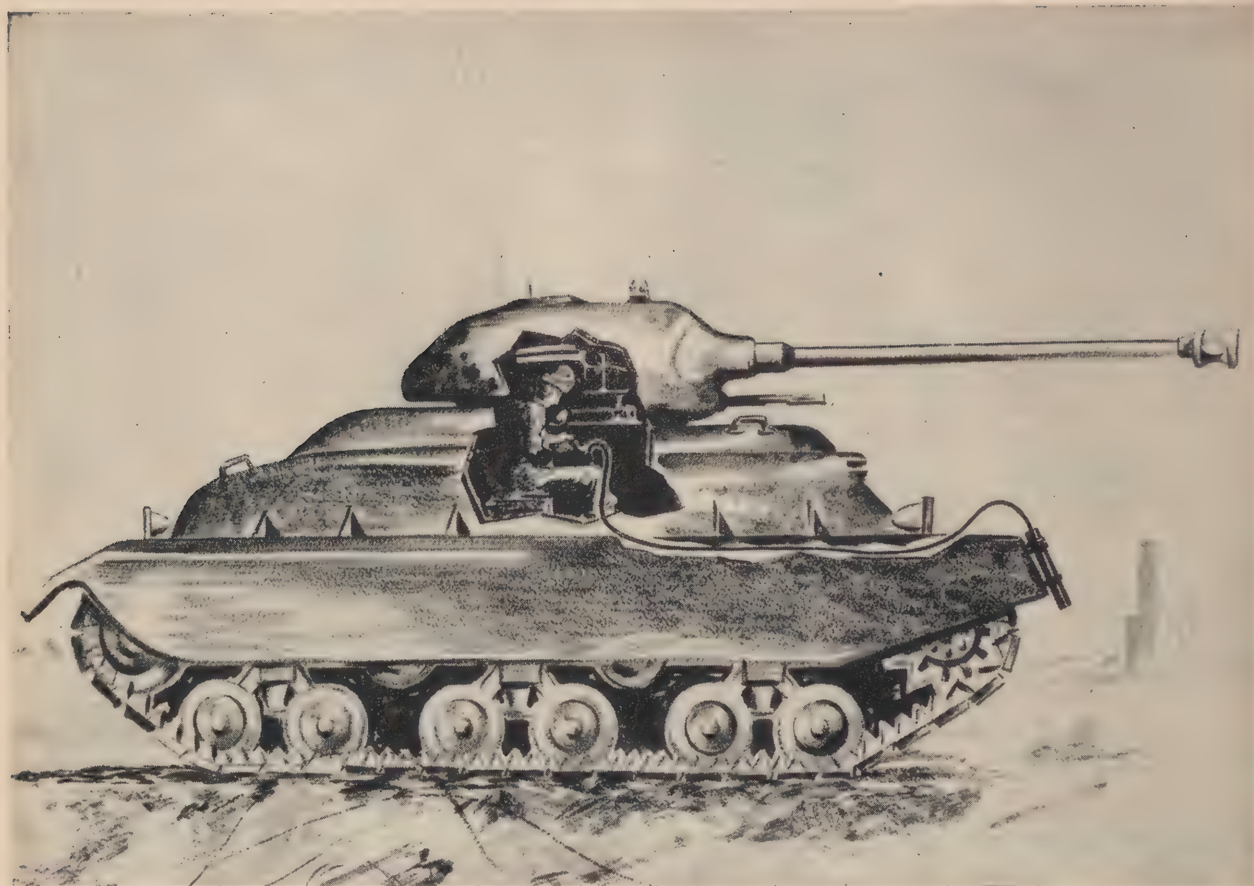


Figure 8.21b. Artist's conception of a survey party utilizing the gamma shielding of tank armor.

8.25. The Geiger detector, like the ion-chamber instrument, can be used for gamma radiation, and also for counting beta particles if the tube has a suitable window. Frequently, the tube is enclosed in a probe connected to the counter itself by a cable, and has a sliding beta shield (fig. 8.25). When the shield is in position, the thin window is covered, and only gamma radiation can enter the counter. With the shield retracted, however, beta particles, in addition to the gamma radiation, can be detected and measured.

8.26. The chief advantage of the Geiger-counter type of instrument is that there is such a considerable degree of amplification within the tube itself, in the formation of the avalanche, that very simple electronic systems are sufficient to detect quite low radiation intensities. Since many counters overload when the pulse rate is very high, this type of Geiger instrument cannot be used for high intensity radiation. However, very small, and consequently less sensitive, Geiger tubes are available for this purpose and have made possible the development of wide-range instruments capable of measurements up to dose rates of 500 roentgens per hour.

Choice of Survey Meters

8.27. In the laboratory, where it is possible to choose the instrument best suited to a particular type of measurement, ion chambers and Geiger counters are employed according to the circumstances. Other types of counters have their specific uses, as, for example, in the detection of alpha particles. For field radiological defense purposes, desirable military characteristics call for a device covering the range from 0.05 milliroentgen to 500 roentgens per hour, which is as small and as light as possible, the weight not exceeding 10 pounds and with no dimension greater than 12 inches. The entire instrument should

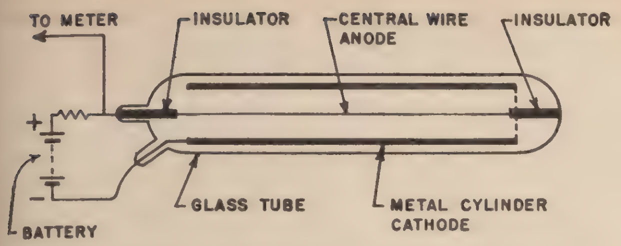


Figure 8.23. Diagrammatic representation of a Geiger tube.

meet the military requirements for a rugged field instrument which can operate under a wide range of operational conditions.

8.28. The radioactive contamination remaining after an atomic explosion emits gamma radiation and beta and alpha particles. An agent used as a weapon in RW would undoubtedly give off gamma radiation and beta particles (ch. 5). In any event, alpha and beta particles will generally be associated with appreciable gamma radiation. Since this radiation is the most penetrating and consequently represents the greatest external hazard to personnel, it is apparent that, at least in the first place, monitoring for gamma radiation is all that is necessary. If the gamma radiation intensity is high, then the contaminated area or equipment is a hazard, irrespective of the alpha and beta particles.

8.29. A survey meter for field monitoring should thus be essentially a detector of gamma radiation. Either an ion-chamber instrument or a wide-range Geiger counter will serve this purpose. When the gamma radiation intensity is low, there may still be a beta hazard (par. 7.58), and a sensitive Geiger counter can be used to detect beta particles as well as gamma radiation. This is possible when the detecting unit has a suitable window with a retractable beta shield. Such a device is particularly valuable for the detection of small sources of radioactive contamination on clothing, equipment, etc., in the decontamination of personnel and equipment.

8.30. It may be concluded, therefore, that for most radiological defense requirements in the field, a single basic wide-range instrument would prove suitable. In

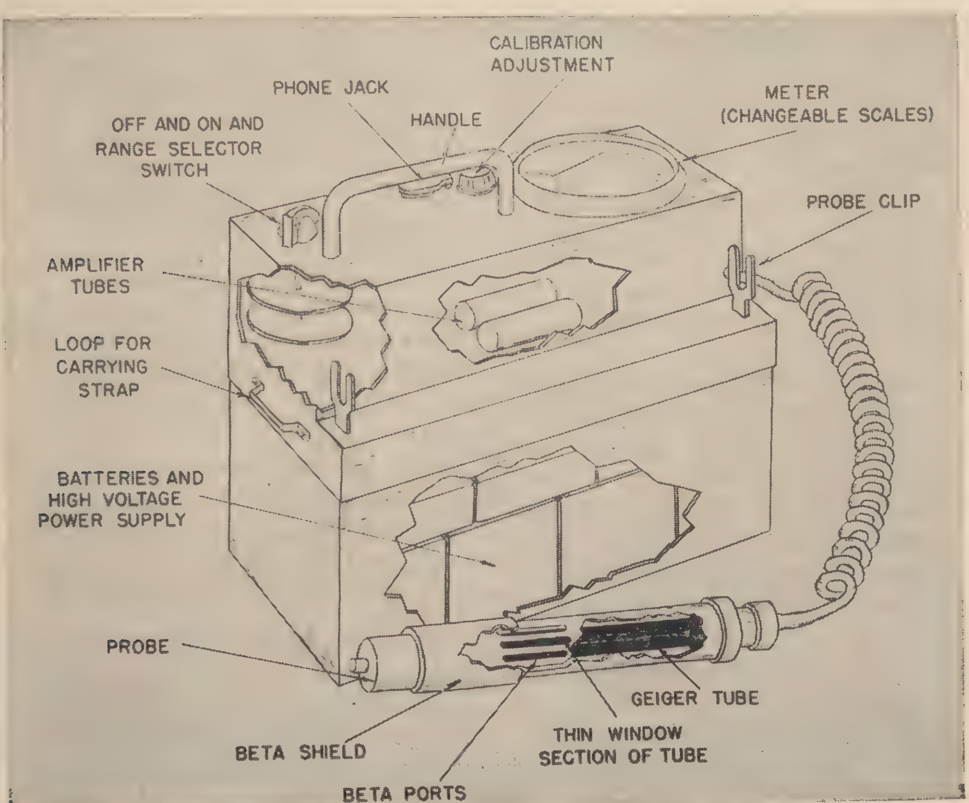


Figure 8.25. Cutaway diagram of a Geiger survey meter.

its simplest form it could be carried by hand, or on a jeep, for monitoring of moderately and highly contaminated areas. By enclosing the detecting unit in a probe, having a long cable attachment to the meter, the device would be suitable for monitoring heavily contaminated areas from an armored vehicle or from an airplane. For specialized purposes, such as monitoring in the course of decontamination of personnel or equipment, a highly sensitive beta-gamma survey meter may be required.

Airborne Survey Equipment

8.31. It will be seen in chapter 9 that a rapid estimate of the radiation hazard in a contaminated area on the ground, without involving undue exposure of personnel, can be made by means of an aerial survey. A drawback is, however, that a measurement taken with an ordinary ground survey instrument in a fast moving airplane cannot be easily identified with a particular area on the ground.

8.32. In order to overcome the difficulty mentioned above, special airborne equipment has been developed which makes possible the determination of the degree of surface contamination existing in a certain area by taking measurements from an airplane flying over the area. This equipment has built-in features which correct for the altitude of the aircraft, and has directional characteristics which enable the operator to key the reading with a definite position on the surface.

DOSIMETERS

General Principles

8.33. Personnel dosimeters, used for indicating the total radiation dosage received by an individual, are of three main types—(1) the pocket dosimeter (or pocket chamber), (2) the film badge, and (3) the phosphor-glass dosage indicator. Pocket dosimeters and film badges are available in either self-reading or nonself-reading forms. The pocket dosimeter is actually a very simple form of ion chamber, for its action depends on the production of ions by the nuclear radiations. However, it has no batteries and associated equipment, and there is no flow of current. The nonself-reading form of pocket ion-chamber is often referred to as a "pocket chamber," while the term "pocket dosimeter" is used for the self-reading type.

8.34. The action of the film badge is based on the fact that nuclear radiation, like light, can affect photographic film. But, while light is unable to penetrate the paper in which the film is wrapped, nuclear radiations, other than alpha particles, are able to do so. Consequently, photographic film with light-proof paper protection can be used for the detection of nuclear radiation without being affected by light.

8.35. The action of the phosphor-glass dosage indicator is based on a different principle from that of the ion-chamber and film-badge types. Gamma radiation produces an internal change in glass which may be detected by a suitable reading device, as will be described in paragraph 8.49.

Pocket Chambers

8.36. The simplest form of pocket ion-chamber is similar to a fountain pen in size and shape. It consists of an outer cylinder, made of a plastic material, the interior being coated with graphite to make it an electrical conductor. A stout wire, or inner cylinder supported at its ends by insulators, runs through the outer cylinder. To use the pocket chamber, it first must be given an electrical charge. This is done by connecting a charger between the shell (positive) and the central wire (negative) of the chamber (fig. 8.36). The chamber is then removed from the charger, and if the insulation is satisfactory, there will be no leakage and the charge will remain unchanged.

8.37. When nuclear radiation enters the chamber, it produces positive and negative ions in the gas. These are attracted to the charged wire and shell, respectively, as described in paragraph 8.18. However, since the battery has been disconnected, there is no flow of current. Instead, the magnitude of the charge is reduced. The decrease in charge is proportional to the total amount (or dosage) of radiation that has entered the chamber. Consequently, if the remaining charge is measured at the end of the exposure, the radiation dosage can be determined.

8.38. The pocket chamber described above requires associated equipment, called a "charger-reader," for charging purposes and for reading the charge before and after exposure. It contains a voltage source and a suitable meter. The scale of the instrument is calibrated so that upon insertion of the pocket chamber, after exposure to radiation,

Figure 8.36. Minometer type charger-reader for pocket chamber.

the dosage is indicated directly in roentgens. One charger-reader can, of course, be used to charge and read many pocket chambers.

8.39. Because of the shell thickness, most pocket chambers are sensitive to gamma radiation only. They are available for various ranges of radiation dosage, from a few milliroentgens to one or two hundred roentgens.

Pocket (Self-Reading) Dosimeters

8.40. When operating in a contaminated area, it may be necessary to know the radiation dosage immediately, and for this purpose, the self-reading pocket dosimeter is used. Like the nonself-reading pocket chamber it consists of an ion chamber, similar to a fountain pen in appearance. To a short, central wire is attached a thin, flexible quartz fiber, the position of which on an interior scale can be read by means of a lens fitted into the end of the cylinder (fig. 8.40).

8.41. To prepare the self-reading dosimeter for operation it is placed in a charger; this provides an adjustable voltage source which is applied between the central wire and the shell. When the instrument is charged in this way, the movable fiber is repelled from the fixed central wire. By proper adjustment of the voltage, the fiber can be set exactly on the zero line of the scale. When nuclear radiation enters the chamber, ions are produced and attracted to the wire and the shell. The charge is thus diminished, and the repulsion of the fiber is decreased. The latter, consequently, moves across the scale, which is calibrated directly in roentgens. By holding the dosimeter up to the light, and looking through the lens, the radiation dosage received at any time can be read off from this scale (fig. 8.41).

8.42. While the dosimeter does not need any associated equipment for reading the exposure, it still requires a charging and adjusting device to set the fiber on the zero of the scale prior to its use.

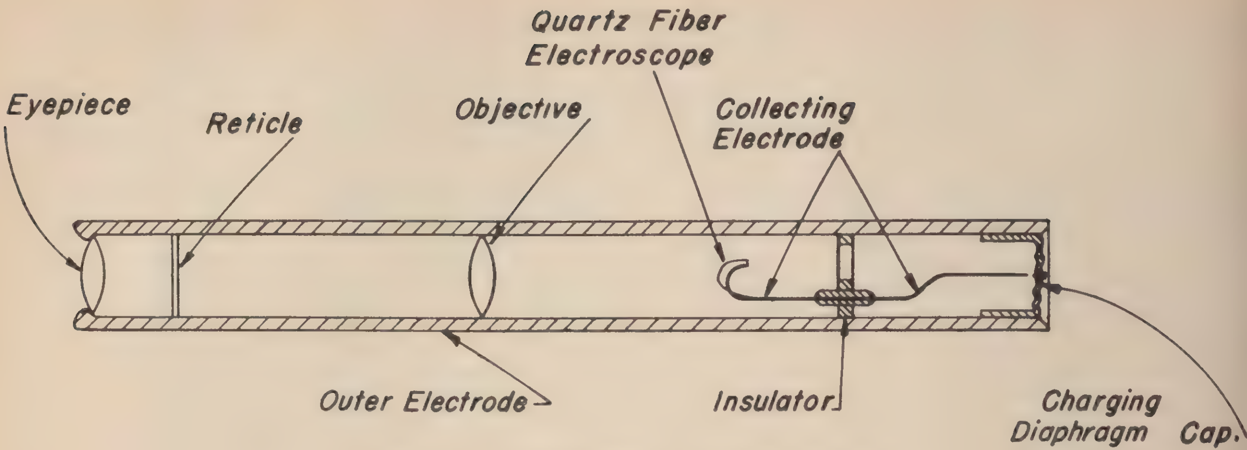


Figure 8.40. Cutaway diagram of the pocket dosimeter.

One such charger can serve many dosimeters. Like the pocket chamber, the self-reading pocket dosimeter can be made to cover various ranges of gamma radiation dosages. Instruments with full-scale readings of 0.2 roentgen (200 mr) to 50 roentgens (50 r) are available.

Photographic Film Badges

8.43. The film badge consists of a small packet containing photographic film sensitive in varying degrees to gamma radiation and beta particles. The films are of the size commonly used for dental X-rays, namely, $1\frac{1}{4}$ by $1\frac{3}{4}$ inches. Each film is packaged in a light-proof paper envelope. An external metal shield fits over a section of this package. The unshielded part of the film is exposed to both gamma radiation and beta particles, while the shielded portion is exposed only to gamma radiation. The metal shield also serves the purpose of making the film more uniformly sensitive to gamma radiation of various energies. Special holders incorporating the shield are made with clips to attach the film badges to the clothing (fig. 8.43). In other cases the whole packet is enclosed in a waterproof envelope and carried in the pocket.

8.44. Exposure of the film to radiation results in changes similar to those produced by light, so that upon development a blackening is observed. The extent of the blackening, or density, of the developed film is a measure of the accumulated dose or total amount of radiation to which it has been exposed. For exact determination of the dosage, an instrument called a densitometer is used to compare the blackening with that of pieces of film of the same type which have been exposed to known amounts of radiation.

8.45. A particular film generally has a limited range of usefulness, in terms of roentgens. Consequently, several films, of different degrees of sensitivity, are placed in one packet. For example, one type of package has three different films covering the ranges from 0.1 to 5 r, 0.4 to 50 r, and 10 to 2,500 r. In this way, a single packet can be used to record small, medium, or large exposures.

8.46. While the film badge is simple and inexpensive, its chief drawback lies in the fact that processing the film and determining the extent of blackening requires the use of a laboratory. Further, considerable time must elapse between exposure to radiation and final evaluation of the dosage. In general, therefore, the simple film badge described above would not appear to be altogether suitable for operational field use. However, this type of film badge is employed for health protection in atomic field tests and laboratories.

8.47. The invention of a self-developing film dosimeter, based on the same principles as that used in the Land (Polaroid) camera, represents an important advance in this connection. It makes possible a self-reading type of film-badge dosimeter. Each packet has incorporated in it a small pod or capsule containing the film processing solution.

Figure 8.41. Method of reading dosimeter by looking through it at the light. Insert shows how a dosage reading of 82 mr would look.

When it is desired to read the dosimeter, the pod is broken by pulling a tab and the solution is thus spread over the film. The latter is consequently developed while still in its holder, the time taken being about a minute. The total radiation exposure or dosage in roentgens can then be estimated immediately by comparing the blackening with a set of standards (fig. 8.47).

8.48. An important requirement for all dosimeters using photographic film is that each batch of film should be standardized. Different lots, even from the same manufacturer, differ sufficiently to make it unwise to use them without calibration. Another characteristic of all film dosimeters is that they give just one reading for each loading. Once the films have been developed, they cannot be used again, even those showing no blackening due to radiation. On the other hand, the developed film, if properly stored, provides a permanent record of the radiation dosage received by the individual.

Figure 8.43. Photographic film badge. Top row, assembly of the film packet. Middle row, attaching lead shield. Bottom row, clip and pocket badges.

Figure 8.47. Self-developing film badge. Left, film holder which can be worn around the neck. Center, the film packet. Right, film packet developed and opened, showing scales against which exposure may be read by comparing lightness of center areas. Black section in center is control strip.

Phosphor-Glass Dosimeter

8.49. The glass dosimeter is a small packet, slightly larger than an identification tag, containing a specially prepared phosphor glass. Exposure of this glass to gamma radiation produces changes in its internal structure so that when the glass is subsequently examined by certain special wave lengths of light, it is seen to glow, i. e., phosphorescence is observed. The phosphorescence can be picked up with a photocell and through an amplifier be made to indicate the radiation exposure of the glass on a meter, calibrated in roentgens. The special light source, photocell, meter, etc., required for reading the glass are contained in an auxiliary device called a "computer indicator."

8.50. As in the case of the ion-chamber instrument, the glass dosimeter gives a continuing indication of the radiation exposure which is not affected

by reading. This type of dosimeter might well be used as a "life time" or over-all operation dosage recorder, in connection with some perhaps more accurate device for day-by-day readings.

Choice of Dosimeters

8.51. In the field or on board a ship or plane the military needs dosimeters for three different purposes with desirable ranges as indicated:

Tactical Dosimeter	5–600 roentgens
Administrative Dosimeter	5–600 roentgens
Technical Dosimeter	0.05–10 roentgens

The tactical dosimeter is intended to furnish commanders with information as to whether their personnel are being subjected to quantities of radiation which in due course of time may make them casualties. This dosimeter will furnish information on which to plan for personnel evacuation and replacement. The tactical dosimeter should be easily read with a minimum of auxiliary equipment; and it should be possible to read it several times during any operation or maneuver without any appreciable delay necessitated by reloading or recharging. In addition to the self-reading pocket dosimeter the self-reading film badge and the phosphor-glass packet might meet these requirements. One or two such tactical dosage indicators would be sufficient for each platoon or company-size unit.

8.52. For various reasons, it may be necessary to keep records of all radiation exposures of military personnel. Consequently, the second field requirement is for a dosage indicator to be used for administrative or statistical purposes. Since one may have to be supplied to each individual, such a device should be rugged, inexpensive, and very light in weight; it should also be reasonably tamperproof. The ordinary film badge, self-reading film badge, and the phosphor-glass packet might be used for this purpose.

8.53. Finally, a technical dosimeter will be required by all individuals who are frequently exposed to radiation in the course of their work; typical examples are instrument maintenance personnel who use radioactive materials for calibration purposes, laboratory personnel, and personnel conducting decontamination operations. Such a dosimeter should be able to indicate radiation doses as small as 0.05 roentgen (50 mr) up to about 10 roentgens. It is desirable, but not essential, that the instrument should be self-reading. These requirements could be met by a film badge or a pocket ion-chamber.

8.54. A general review of the situation suggests that if the logistic and economic aspects could be ignored, a different type of dosage indicator might be used for each purpose. For tactical purposes self-reading, pocket dosimeters, which can be read continuously without adjustment would appear to be most suitable. The administrative or statistical requirements could well be met by a simple film badge or the phosphor-glass dosimeter, while some form of pocket ion-chamber would be satisfactory for technical uses.

8.55. For use in the field, however, the problems of maintenance, supply, etc., would be simplified by the use of a standard type of instrument capable of certain modifications for specific purposes. The self-developing film badges offer one possible solution. Two different kinds of cases or holders would be required: one which would permit spreading the processing chemicals, as described in paragraph 8.47, and another which would not. The film packets carried in the holders would be of two types—one of high dosage range, from 5 to 600 roentgens, and the other of low range, from 0.05 (50 mr) to 10 roentgens.

8.56. The tactical dosimeter, required in small numbers, might consist of several packets of film of high dosage range in a self-developing holder. All the films would be exposed simultaneously to the radiation, and the various individual packets would be developed at intervals. In this way, a unit commander would keep abreast of the approximate accumulated dosage received by each of the men under his command.

8.57. For administrative purposes, each individual could wear the same type of film badge, but only specified persons would have a device permitting film development. The person responsible for the development might also be responsible for recording the exposures. Finally, the technical dosimeter would contain self-developing film packets of low dosage range.

Dosimeters under Development

8.58. A dosage indicator of still another type, which is being investigated, is called a chemical dosimeter. Nuclear radiations are known to bring about chemical changes, and reactions are being sought which will be accompanied by definite color changes either of a solid substance or of a solution. By matching the color with that of a calibrated chart, it might be possible to determine accumulated radiation dosages.

8.59. To provide a record of the total accumulated dosage, and also of the radiation intensity (dose rate), inside an aircraft flying through a radioactive field, an airborne gamma dosimeter is being developed. The equipment is expected to consist of a special ion-chamber detector, and the associated computer, indicator, and recorder units. It may be adapted to give a warning signal when a predetermined total dosage has been received by the operating crew of the plane.

Nonportable Equipment

8.60. For field use, monitoring equipment must be simple and hand-portable, but in laboratories and other more or less permanent installations more elaborate devices of a nonportable character can be used. These would be available for the measurement of alpha particle intensities, and for other purposes related to radiological defense.

8.61. Alpha particle determination is very difficult under field conditions, and fortunately, this is not necessary. As long as a serious external gamma radiation hazard exists, there is no need to be concerned about alpha particles. But some time after an atomic explosion, when the intensity of the gamma radiation has fallen off considerably, alpha emitters, especially plutonium, may represent an internal hazard. Samples of suspected material can then be taken to the laboratory for examination.

8.62. After an atomic attack, the contamination would inevitably be due to the fission products together with unchanged uranium or plutonium. The nature of the contamination, and of its radiation properties, would thus be essentially known. In the event of an RW attack, however, the identity of the agent could not be determined without a proper radiological and chemical analysis. This could be done in mobile field laboratories. The laboratories are trailer-mounted, mobile, radiochemical facilities which are expected to be available to commanders of large units.

Logistic Considerations

8.63. It is evident that radiological monitoring introduces a number of additional logistic requirements. In addition to the necessity for supplying each unit with the required number of survey instruments and dosimeters of various types, the problems of maintenance and repair must be borne in mind. The batteries used in survey meters have a limited life and they must be tested and replaced from time to time. The same is true of the vacuum tubes used in amplifying circuits. The particular kinds of tubes required will depend on whether the dose-rate meter is of the ion-chamber type or of the Geiger-counter type.

8.64. Repair and calibration of survey meters will be necessary from time to time. Consequently, a certain amount of special training will be necessary for personnel assigned to maintenance of the instruments.

8.65. The logistic requirements for dosimeters will depend on the type used; these will be simplified if, as suggested above, it is found possible to employ one type of personnel dosage indicator for all purposes. Any auxiliary devices, such as chargers, readers, or processing equipment, which may be necessary, must, of course, be furnished in adequate numbers and will require maintenance.

SUMMARY

Radiological defense is a command responsibility which introduces some new problems into the military organization. It is, in many respects, similar to defense against chemical agents. The first step in radiological defense is to recognize the existence of the hazard and to assess its importance. Preliminary deductions concerning the hazard can be made by observing the type of burst.

Radiation is detected and measured by devices known as radiac instruments (or radiacs). The process of detection and measurement is called monitoring. Survey meters are used to determine the radiation dosage rate or intensity; this is a measure of the external radiation hazard. The total dose received by an individual over a period of time is determined by means of a suitable dosimeter.

Two types of survey meters are in general use for radiological defense; these are the ion chamber and the Geiger counter. Both are suitable for measuring gamma radiation and can be adapted to detect beta particles in addition. In the Geiger counter there is a considerable degree of internal amplification and so it can be used to detect very low radiation intensities.

Personnel dosimeters are of three main types—the pocket ion-chamber, the film badge, and the phosphor-glass dosage indicator. Pocket ion-chambers and film badges can be self-reading or nonself-reading, and can be adapted to cover various dosage ranges. The phosphor-glass indicator would be particularly suitable for determining total dosages received over an extended period.

Radiological monitoring introduces a number of additional logistic requirements in connection with the supply, maintenance, and repair of radiac instruments and auxiliary devices.

Chapter 9

MEASUREMENT AND EVALUATION OF RADIOLOGICAL HAZARDS

INTRODUCTION

Importance of Radiological Surveys

9.01. An atomic attack on military personnel, equipment, or installations, whether it be on land or at sea, will place a tremendous strain on the available damage control, rescue, and rehabilitation facilities. The problems may be greatly increased in the event of a subsurface burst, for the damage to structures and matériel will be accompanied by radioactive contamination. In these circumstances, casualties will be reduced and wasted effort avoided by the proper measurement and evaluation of the radiological hazard. Such measurement and evaluation will be command responsibilities of the greatest importance. Even after an air burst, when the residual contamination with radioactive materials will be relatively small or negligible, some monitoring will be required to reassure personnel.

9.02. In order to permit intelligent operational planning following the attack, it will be necessary to obtain information concerning the radiological hazard as quickly as possible. This preliminary information will permit a rapid estimate of the situation to be made. It will be supplemented by more complete monitoring, a short time after the explosion when the radioactivity has fallen off appreciably. As seen in paragraph 2.27, the activity of the fission products decays very rapidly in the first few hours after the explosion. Consequently, more useful information, with less danger to the personnel concerned, can be obtained if the detailed procedure can be somewhat delayed.

9.03. After an RW attack the radiological survey requirements would be quite similar to those following a contaminating atomic burst. A rapid preliminary survey would be followed by more careful monitoring of the contaminated area. In order to identify the RW agents, samples of the contamination should be collected and forwarded to a laboratory for analysis.

Outline of General Procedure

9.04. To facilitate operations in a contaminated area, three steps are necessary—(1) surveying or monitoring the area for radioactivity, (2) marking contaminated regions and objects, and (3) controlling operations, traffic and personnel within the area. The general principles are outlined here, and each step is considered in more detail below.

9.05. The monitoring process involves locating the contamination by means of suitable instruments which indicate the residual radioactivity in terms of the radiation intensity or dose rate. It also includes the evaluation and interpretation of the survey data. As indicated above, monitoring is usually carried out in stages. There is first the rapid preliminary reconnaissance, followed by a more detailed survey. Later, individual objects may be subjected to supplementary monitoring.

9.06. The next step is marking the surveyed areas and objects to show the presence of radioactive contamination. Standard markers (par. 9.36) should be employed for this purpose. In addition, supplementary markers, suitably colored, may be used, if desired, to indicate the relative hazard as determined by the intensity readings obtained by the monitors.

9.07. The third stage is control, which involves continuous supervision of operations in and around the contaminated region to insure the accomplishment of essential missions with a minimum hazard to personnel. Control also includes an extension of normal traffic control, namely—segregating clean personnel and equipment from those which have become radiologically contaminated.

RAPID RADIOLOGICAL RECONNAISSANCE

Aerial Survey

9.08. The most rapid method of estimating the extent of the radiological hazard in the early stages will be by means of an aerial survey. The great advantage of such a survey is that it can be carried out regardless of the destruction or the radiation intensity in the bombed area. Because of their long range in air, gamma rays coming from radioactive contamination on the surface can be detected by sensitive instruments at the height of several thousand feet. Planes carrying ordinary survey meters or special devices, as described in paragraph 8.32, could fly over an affected area in accordance with a

predetermined pattern, and record the gamma radiation intensities encountered. Slow-flying liaison aircraft or helicopters would be particularly useful in this connection. The initial flight pattern might be at an altitude of 1,000 feet, and this could be followed by similar flights at lower levels if necessary.

9.09. From the radiation intensities measured, at a known altitude, it is possible to obtain a rough estimate of the dosage rate, in roentgens per hour, which would be encountered on the surface of the ground or water. The exact ratio between the reading in the plane and the dose rate on the surface will vary depending on the nature of the terrain, the contamination, and the instruments used. Experimental and theoretical studies have indicated that the dose rate on the surface will be somewhere between 100 to 1,000 times the reading at 1,000 feet. Figure 9.09 gives some correction factors which can be used, when no other specific information is available, to convert radiac readings measured at various altitudes to the dose rate at ground level.

9.10. Monitoring from a plane suffers from the fact that the speed of the aircraft makes it difficult to associate the radiation intensity as measured in the air with a particular area of ground. In general, the intensity of the gamma radiation as observed in the air will represent the average from a considerable area. Another cause of uncertainty is the altitude of the plane. If the readings are to have any significance, they should be taken at a constant distance above the surface. The foregoing comments point up the desirability of using slow-flying aircraft for aerial radiological surveys, especially when using ordinary ground survey type instruments. It would consequently be advantageous to use the special airborne ground survey equipment described in paragraph 8.32.

Preliminary Ground Reconnaissance

9.11. The aerial survey is important because it can provide valuable information which might be impossible to secure in any other way. Nevertheless, it must be emphasized that the aerial survey can, of necessity, serve only as a rough guide. It is not a substitute for, and must be followed by, a survey on the ground at least in the case of those areas which are of any military importance. Early ground monitoring, which would be supplementary to, or even independent of, the aerial survey, could be carried out by means of a tank or armored car, if conditions permit its use. The thick metal walls of such a vehicle would offer a measure of protection from the gamma radiation to monitoring personnel. With a detecting unit in a probe mounted on the exterior of the vehicle, as described in paragraph 8.30, it may be possible to approach and determine the extent of a heavily contaminated area. (See fig. 8.21b.)

9.12. It should be understood that the airplane, tank, or other means of transportation, and the associated personnel employed in making the radiological hazard reconnaissance, will have to perform those duties as part, and not independently, of a general reconnaissance of blast and fire damage, and casualties to personnel. The situation in these respects, as well as the radiation hazard, will be reported to the control center by the most rapid means of communication available. This will make possible more effective over-all planning of damage control and rescue operations.

9.13. Following an atomic attack, it may be necessary to send parties on emergency missions into the affected area, concurrently with the reconnaissance groups. Operations of this kind will be limited to those of an urgent character, such as to attain or hold a military objective, to rescue trapped personnel, to administer first aid, to put out fires, or to perform emergency repairs of bridges, utility lines, etc. When feasible, the party should include an individual to act as a monitor, whose prime responsibility will be to see that his party does not receive more than the established permissible dose of radiation. However, the monitor should, if possible, make and report more detailed observations concerning the radiation intensities at various points along the routes traveled. For this purpose he should carry a survey meter, in addition to personnel dosage indicators.

Establishment of Perimeters

9.14. The purpose of the monitoring parties entering a contaminated area soon after an atomic attack will be to read, record, and report intensities of radiation encountered at various points. These will enable personnel at the control center to plot the data and thus to determine the general outline or perimeter of the contaminated areas. In addition, they can establish a danger perimeter at a radiation intensity,

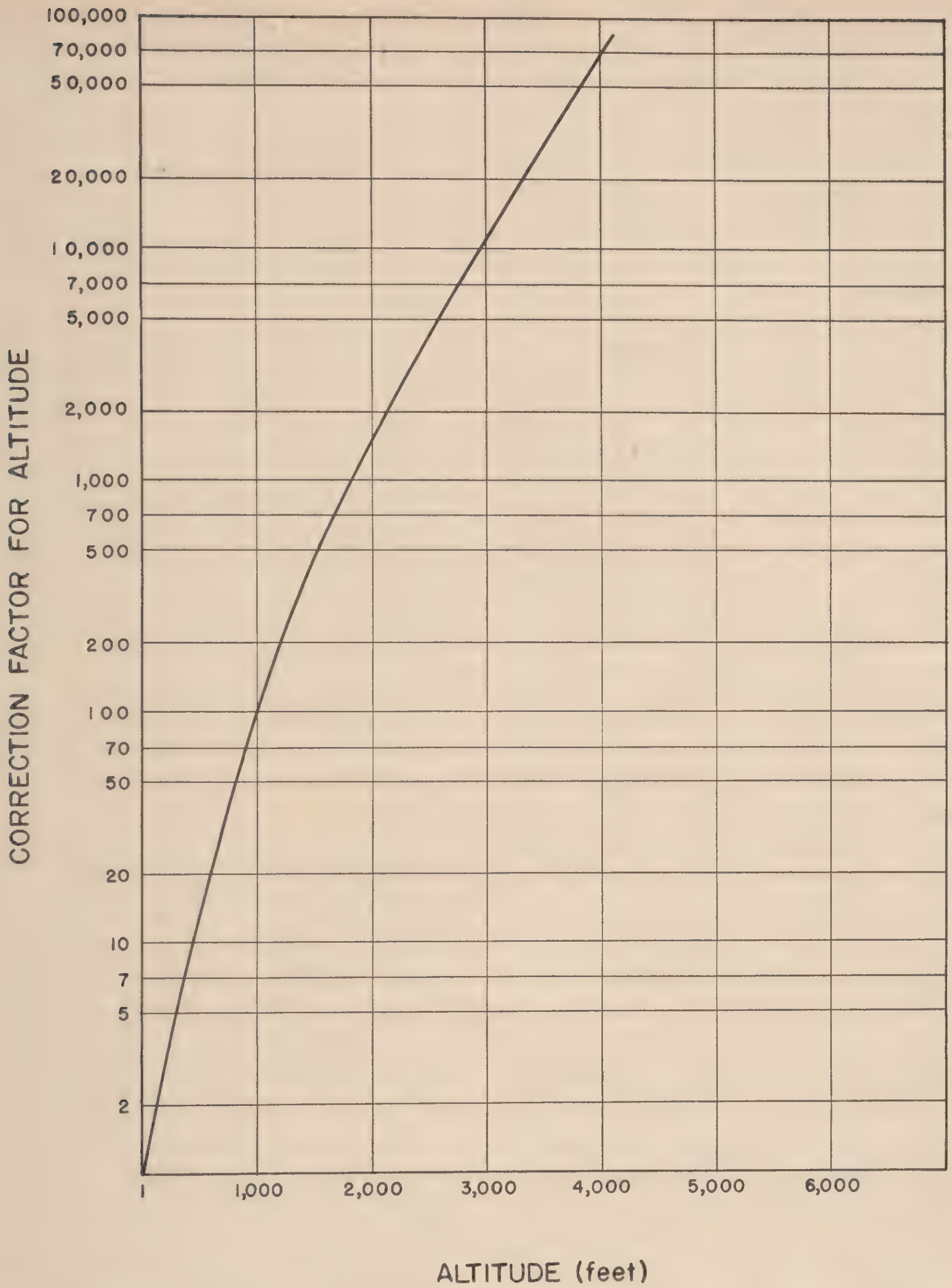


Figure 9.09. Factors for multiplying radiac readings taken in survey aircraft, to obtain dose rates at the surface.

say 100 roentgens per hour, which the responsible commander will have arbitrarily established, based on the recommendation of his appropriate staff advisers (ch. 13).

9.15. After the first survey parties have measured and reported readings which allow the general extent of the contaminated areas and the approximate location of the danger perimeter to be plotted, subsequent survey parties can proceed with more detailed monitoring of the area as a whole. The purpose of these subsequent surveys is to —(1) find the radiation level of specific objects or locations within the contaminated area which are of interest to the commander; (2) locate regions of higher than average intensity ("hot spots"); and (3) establish with greater accuracy the position of the outer perimeter of contamination and the danger perimeter. These subsequent survey parties should, in addition, carry with them signs and marking equipment with which they can designate the outer perimeter of the contaminated area, access roads which are clear of obstructions, the location of "hot spots," and the danger perimeter (par. 9.35).

9.16. Monitoring after an atomic attack should be restricted to areas of military importance. An area of no military value, irrespective of the extent of its contamination can be ignored, provided it is clearly marked in a suitable manner.

DETAILED RADIOLOGICAL SURVEY

Survey Techniques

9.17. In performing the radiological survey of an area, attention must be paid to certain matters. Monitors must be trained in a definite technique of holding the radiac instrument or its probe always at the same distance from the surface or the object to be monitored. Unless they do so, the readings taken will not represent a true picture of the radiation intensity.

9.18. Further, it must be borne in mind that the level of contamination will vary among locations, depending on soil conditions, type of surface contaminated, and the positions of objects within the area. A piece of equipment exposed directly to the base surge and fall-out may show a higher radiation intensity than one nearby which has been sheltered in some way. Objects having poor drainage will frequently give higher intensity readings than those having good drainage. In a necessarily hurried survey of an area, a monitor may record the intensity at only one point as representative of an entire area. A single observation is, obviously, of little value by itself; it is only when a relatively large number of readings are plotted, on a map or an overlay, that the contamination of the area as a whole can be evaluated.

9.19. Monitoring personnel who form part of reconnaissance teams should be equipped to record the intensity, time, and place of each reading and, if feasible, to report this information by radio or other rapid means of communication. As stated above, the information becomes useful only when it is plotted and correlated with other information covering the area as a whole. Except perhaps in a few front-line situations, survey parties entering a contaminated area will probably use the existing road network. They will use vehicles, if possible, since this will permit the most rapid approach and withdrawal. In addition, use of the road net will facilitate the location, by plotting personnel, of the positions at which readings are taken.

9.20. If the center of the impact area is known, survey parties should proceed toward it taking periodic readings until a designated point or radiation intensity is reached. They will then return, preferably by another route, in order to obtain a second series of readings through a different area. While it might be desirable, it will probably not be possible, for survey parties to follow a "contour" at a fixed radiation level through or around the contaminated area. Survey parties entering the area at later times should attempt to use other portions of the road net in order to extend the knowledge of the radiation levels in the area as a whole, and as part of the general reconnaissance mission to determine passability of roads and accessibility of objects or installations in the area.

9.21. As the area surveys continue, and as it becomes desirable for military reasons, the operation gradually passes into what has been called the "supplementary survey." This involves detailed monitoring of such things as water and food supplies, of bodies of water, such as bays, lakes, harbors and sizeable reservoirs, and of specific buildings and in-

stallations which it might be desirable to occupy later. The need for these supplementary surveys, to be described briefly below, will be determined by military requirements.

Detection of Airborne Hazard

9.22. When operations continue in a contaminated area, for say a week, following an atomic bomb attack, the external radiation hazard will have decreased by natural decay, permitting rehabilitation operations. Personnel can then remain in the area for longer periods without undue risk. At this time it will become of increasing importance to take air samples in the contaminated area, in order to give the commander information as to where he should require personnel working in the area to wear respirators or gas masks, and special clothing, as protection (par. 10.62). It should be remembered that initial survey parties operating immediately after a contaminating burst must assume that airborne contamination exists and should wear masks of some type. However, during later operations, masks will be required only for dust-producing operations in contaminated areas.

Radiological Survey of Water Areas

9.23. While the foregoing section has applied more particularly to the radiological survey of a land area, much of what has been said will apply also to the monitoring of bodies of water. A preliminary survey should, if possible, be made from slow-flying aircraft, after which more detailed survey operations can be carried out using small, fast-moving, surface craft.

Special Monitoring Techniques

9.24. In certain circumstances, special monitoring measures may be required; for instance, parts of an area may be found impassable because of fires, debris, or enemy action. Two techniques, in particular, are aircraft monitoring and telemeter monitoring. Slow-flying aircraft, especially helicopters, equipped either with special airborne automatic recording instruments (ch. 8), or carrying a monitor equipped with standard survey instruments, may be used to determine the extent of a contaminated area, and to obtain a general idea of the levels of contamination. An airborne monitor should record and report, so far as possible, the same information which a ground monitor would report, that is, the time, location, and intensity of his readings, together with an indication of his altitude over the spot.

9.25. A second technique involves the use of telemetering devices. These devices may be dropped in the area by aircraft or, under special circumstances, fired by rocket or from a mortar. The instruments automatically take readings of the intensity where they land, and transmit these readings by radio to a receiver located either in an aircraft or at a control point outside the contaminated area. One of the difficulties in the use of telemeters is the problem of locating their positions with accuracy. In general, this must be done either visually or by radio direction finders.

Cloud Tracking

9.26. Another form of radiological monitoring which may be desirable under some circumstances is tracking the atomic cloud. If air operations are required in the vicinity of an atomic explosion, the avoidance of the radioactive cloud will be important. Flight through the cloud would be exceedingly dangerous within the first 10 minutes following the explosion, and caution should be exercised to avoid the atomic cloud for an hour or more. Knowledge of the cloud location will facilitate safe air operations.

9.27. Tracking of the cloud may also make possible evaluation of the hazard from downwind fall-out, particularly in the case of subsurface bursts, or if rain falls soon after air or surface bursts. A knowledge of the areas which might have been subject to contamination will permit concentration of monitoring operations in the proper locations and greatly simplify the radiological defense problems. It will furthermore facilitate offensive operations designed to take quick advantage of an attack with atomic weapons.

9.28. Meteorological forecasts and information concerning wind velocities and directions at different altitudes can also be employed to determine the probable path of the atomic cloud. Treatment of such data by the procedure known as "meteorological trajectory analysis" ("radex" plotting) will make possible rough estimates of the trail of the radioactive fall-out from the atomic cloud and of the time of its arrival at various distances from the explosion center.

9.29. Reports concerning the radiological condition of the atmosphere should be transmitted to the proper aircraft control center. Here, the radiation pattern can be plotted on a map of the area over which the center has control. The operations officer will then have an actual picture of the atomic cloud and its probable spread. By means of radio he may suggest course changes directly to pilots or he may instruct them to gather further information in the event that the picture is incomplete.

Evaluating Results of Detailed Survey

9.30. As each radiation intensity reading is received at the control center it is corrected to some standard time after the atomic explosion; a convenient time for this purpose is 1 hour. This value is then plotted at the appropriate position on a map or chart of the contaminated area, or on an overlay. Points of equal radiation intensity, that is, where the dose rates are equal, are then joined to give a series of lines similar to the contour lines on a relief map (figs. 9.30a and b).

9.31. It is because of radioactive decay that all readings should be corrected to a common time after detonation. It would be misleading to connect a point, at which the dose rate due to fission products is 100 roentgens per hour at 30 minutes, with one where this same dose rate is observed at 60 minutes after the explosion. The radiation intensity is actually greater at the second of the two places, because, at 60 minutes after the explosion, the dose rate at the first place would have decreased from 100 to about 43 roentgens per hour.

9.32. The conversion of dose-rate readings to a standard time can be done by means of the chart in table 9.32, which is based on the fission product decay equation given in paragraph 2.26.[1] The extreme left column represents a series of times after the explosion, and the other columns indicate the corresponding radiation intensities of various quantities of fission products. The intensities may be taken in any convenient units, e. g., roentgens per hour (r/hr.).

9.33. Suppose that at 3 hours after an atomic explosion the dose rate as observed at a certain point is 30 r/hr. To determine the dose rate at 1 hour after the explosion, first find the line indicating "3 hours" in the left-hand column, and follow this line horizontally until the reading nearest to 30 r/hr. is found. This is seen to be 27 r/hr. In the same vertical column, it is found that at 1 hour after the explosion the dose rate would have been 100 r/hr. Hence, for 30 r/hr. at 3 hours, the dose rate at 1 hour after the explosion would be $100 \times 30/27$, i. e., roughly 110 r/hr.

9.34. Once the dose-rate map has been prepared as described above, it is possible to determine, approximately, the dose rate for any location at any time after the explosion, with the aid of table 9.32. In addition to the decrease due to radioactive decay, allowance should be made for possible effects of weathering on land, and of the currents in contaminated water. Even in a more or less enclosed body of water, such as Bikini lagoon, settling of the radioactive material to the bottom will tend to decrease the activity (par. 4.38). Estimates obtained, after taking these factors into consideration, should be checked by actual measurements on successive days. It will then be desirable to change the readings on the map from time to time, at noon each day, for example, in order to keep the values reasonably up to date.

Marking the Contaminated Area

9.35. Marking refers to indication of radioactive areas by means of various markers. As in an area contaminated by chemical warfare agents or in a mine field, it is necessary to mark the area in order to warn approaching personnel and vehicles of the existence of a hazard. It may be desirable that spots having radiation intensities above the general level of the surrounding area should be marked in a special way. In addition to indicating the areas of contamination, equipment and matériel removed from these areas should be marked.

9.36. Standard markers for designating areas contaminated with radioactivity have been agreed upon by the Armies of the United States, the United Kingdom, and Canada.[2] These markers are triangular in shape. The surface facing away from the contamination, i. e., toward a person approaching the area, is divided into three triangles by black lines

[1]For a more exact graphical method, see appendix II.

[2]SOLOG Agreement 4, "Marking Contaminated Areas," Items BA3B1 and BA3C, November 1950.

Table 9.32. Fission Product Activities at Various Times after an Atomic Explosion

Time after explosion	Roentgens per hour																			
6 m.	16	32	66	95	127	159	318	477	636	795	954	1272	1590	—	—	—	—	—	—	—
12 m.	7	14	28	41	55	69	138	207	276	345	414	552	691	1380	—	—	—	—	—	—
18 m.	4.3	8.6	17	25	34	43	86	129	172	216	259	344	431	862	1290	—	—	—	—	—
30 m.	2.3	4.5	9.1	13	18	23	45	68	91	114	136	182	227	456	681	908	1140	—	—	—
42 m.	1.5	3.0	6.0	9.1	12	15	30	46	61	76	91	122	152	304	456	608	760	912	1220	—
1 h.	1.0	2.0	4.0	6.0	8.0	10	20	30	40	50	60	80	100	200	300	400	500	600	800	1000
1 h. 30 m.	0.6	1.2	2.4	3.7	4.9	6.1	12	18	24	31	37	48	61	122	183	244	305	366	488	610
2 h.	0.4	0.9	1.8	2.6	3.5	4.4	8.7	13	18	22	26	35	44	87	131	175	219	262	350	437
3 h.	0.3	0.5	1.1	1.6	2.1	2.7	5.4	8.0	11	13	16	21	27	54	80	107	134	161	214	268
5 h.	—	0.3	0.6	0.9	1.2	1.5	2.9	4.4	5.8	7.3	8.7	12	15	29	44	58	73	87	116	145
7 h.	—	—	0.4	0.6	0.8	1.0	1.9	2.9	3.9	4.9	5.8	8	10	19	29	39	49	58	78	97
10 h.	—	—	—	0.4	0.5	0.6	1.3	1.9	2.5	3.2	3.8	5.1	6.4	13	19	25	32	38	51	64
15 h.	—	—	—	—	0.3	0.4	0.8	1.2	1.6	1.9	2.3	3.2	3.9	7.8	12	16	19	23	31	39
20 h.	—	—	—	—	—	—	0.6	0.8	1.1	1.4	1.7	2.2	2.8	5.5	8.3	11	14	17	22	28
30 h.	—	—	—	—	—	—	0.4	0.5	0.7	0.9	1.0	1.4	1.7	3.4	5.2	6.9	8.6	10	14	17
40 h.	—	—	—	—	—	—	—	0.4	0.5	0.6	0.7	1.0	1.2	2.4	3.6	4.8	6.0	7.3	9.6	12
60 h.	—	—	—	—	—	—	—	—	—	0.4	0.5	0.6	0.7	1.5	2.2	2.9	3.7	4.4	5.9	7.4
100 h.	—	—	—	—	—	—	—	—	—	—	—	0.3	0.4	0.8	1.2	1.6	2.0	2.4	3.2	4.0
200 h.	—	—	—	—	—	—	—	—	—	—	—	—	—	0.4	0.5	0.7	0.9	1.1	1.4	1.8
400 h.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.3	0.4	0.5	0.6	0.8
600 h.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.4	0.5

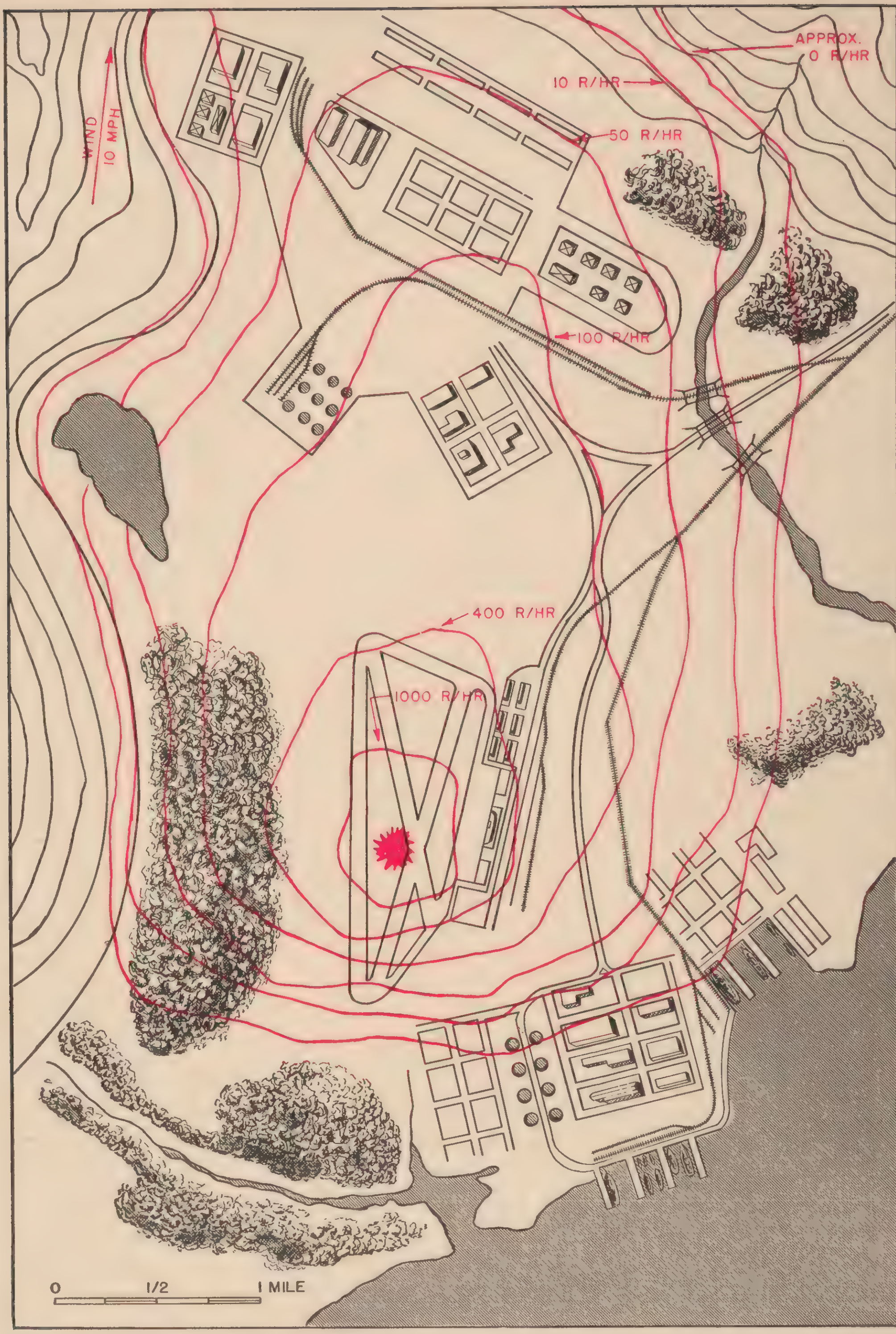


Figure 9.30a. Map of a typical military base in a forward area. Shown in red are contours of equal radiation intensity as they might be plotted at control center, from monitoring data corrected to one hour after detonation. An underground burst, with 10 m.p.h. surface wind, was assumed.

Figure 9.30b. Map of a typical municipal and harbor area. Dose-rate contours show monitoring data corrected to one hour after detonation as in figure 9.30a, except that an underwater burst with 5 m.p.h. wind was assumed.

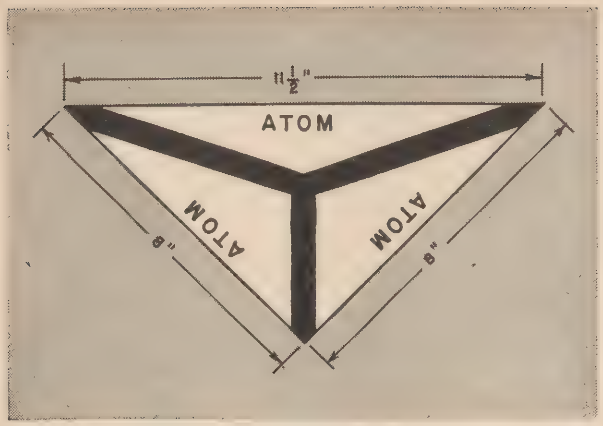


Figure 9.36. Standard markers for areas contaminated with radioactive materials.

on a white background, as shown in figure 9.36. The word "ATOM" is written or painted in black in three positions, so that it can be read erect regardless of the position of the triangle. The back surface of the marker, facing inward toward the contamination, is white, and upon it should be entered details of the contamination and the date.

9.37. The standard marker must always be used to indicate a contaminated area or object. However, in certain circumstances a commander may wish to indicate the *relative* radiation hazard at various places. To do so, he may use supplementary, additional markers, but it should be understood that such markers must never replace the standard markers.

9.38. As supplementary markers for local use, red-colored signs or red paint may designate a highly contaminated area, while yellow would indicate a lower intensity of radiation. Luminous discs or, when the situation permits, illuminated signs of some kind may be used for night visibility.

9.39. Access routes for operation in a contaminated area should be provided and clearly marked. The best routes will be determined on the basis of the detailed radiological survey, and should be delineated by appropriate markers.

Control Measures

9.40. To minimize danger to personnel and to prevent the spread of contamination, the movement of personnel, vehicles, and matériel into and out of the contaminated area should be controlled to the maximum extent consistent with the existing military situation. This can probably be best accomplished by establishing control points situated on the access routes. In addition, it may be considered desirable to establish control over specific places where the radiation intensity is high.

9.41. Authorized personnel, conducting necessary operations in and near the contaminated area, should leave and enter the area through a control point. A suitable change station should be set up if practicable, so as to permit decontamination of personnel before entering the clean area. Details of such a station are described in chapter 10. Vehicles should be required to pass through a control point, and be permitted to leave the area only if it is certain they carry no appreciable contamination.

9.42. All matériel removed from, or that has been used in, the contaminated area should be collected at a control point. Here the matériel can be monitored and separated into contaminated and uncontaminated. The uncontaminated may be moved out, while the contaminated may be treated in the most appropriate manner, usually by decontamination or storage to permit the activity to decay (ch. 11).

SUPPLEMENTARY MONITORING

General Considerations

9.43. Some time after the detailed radiological survey has been made, and the first steps are being taken toward rehabilitation, commanders will have to make decisions concerning the eventual necessity for decontaminating or for temporarily evacuating contaminated structures. Equipment and supplies may also have to be decontaminated or set aside for a time. Further, questions will arise with regard to the continued employment or evacuation for decontamination of personnel affected by the attack. To help in arriving at the proper decision, detailed monitoring of structures, equipment, supplies, personnel, etc., will have to be carried out.

Food and Water Supplies

9.44. One of the most urgent matters will be the examination of food and water supplies to prevent possible ingestion of radioactive material. Unpackaged food that has been exposed in a contaminated area may not be worth monitoring.

Nevertheless, meats can be trimmed or skinned to remove surface contamination. Sealed or packaged foods, either in cans or glass jars, may be used, provided the exterior of the container is thoroughly cleaned before it is opened. Food which cannot be decontaminated should be disposed of.

9.45. Small water supply sources, such as open wells, potable water tanks, scuttlebutts and Lister bags, should be monitored externally. If there are signs of contamination, the water itself should be examined. It will be seen later (par. 10.84) that water (and food) may be appreciably radioactive yet acceptable for consumption, especially under emergency conditions. Consequently, simple, wide-range survey meters will be suitable for monitoring food and water.

9.46. Even if an atomic bomb is actually detonated in a reservoir, river, or other source of drinking water, or the water is deliberately contaminated by an RW agent, the chances of contamination of large, public water supplies on land to a degree sufficient to constitute a health hazard is considered to be negligible. Nevertheless after a contaminating attack, it would be advisable to check the drinking water supply before use.

Road, Structures, Installations, Etc.

9.47. In general, roads will be monitored in the same way as land areas, although special attention should be paid to locations, such as culverts, drainage ditches, etc., where contamination is likely to collect. The roofs and overhanging parts of buildings also fall in this category. Any portion of a building that is to be used for the storage, preparation, or consumption of food must be monitored with the utmost care.

Ground Forces Equipment

9.48. All forms of armament or equipment in the contaminated area which are handled or worn by personnel should be subjected to detailed examination before use. This applies to tanks, weapons, trucks and other vehicles, electronic devices, and clothing and other personal equipment. In monitoring, special attention should be paid to exterior portions, and especially to recesses, of any piece of armament or equipment.

Naval Equipment

9.49. The monitoring of all weather decks on ships and other craft is essential, but monitoring of the interior will depend on the penetration of the base surge and on the entry of contaminated water. A general radiological survey will provide some indication of the contaminated regions, and more detailed monitoring will then be carried out where it is deemed necessary. The remarks made above concerning the careful examination of places associated with the preparation of food are particularly applicable to the galley, pantries, food-storage and messing compartments, etc.

9.50. Details were given in chapter 6 of the parts of a ship and its equipment which are likely to become contaminated after an underwater burst. These are the regions where detailed monitoring will most probably be needed. Special attention should be paid to hollows, crevices, and rough spots, to places where paint is chipped or rough, and to piles of porous materials, such as canvas and cordage. Salt-water lines, ventilation ducts, and air casings of boilers should not be forgotten.

Air Forces Equipment

9.51. Aircraft may become contaminated, as the result of a subsurface burst or by flying through the atomic cloud. Oily or greasy surfaces, cracks, recesses of various kinds, and overlapping riveted joints are places where radioactive particles are likely to adhere. The exterior portions of the fuselage of a plane are most likely to be contaminated and, consequently, they should be thoroughly monitored. Air intakes of both reciprocating and jet engines must be given special attention, particularly if the aircraft has flown through a contaminated atmosphere. Monitoring of the interior of the plane should be conducted to determine whether the contamination has entered or not.

Laboratory Measurements

9.52. There are certain kinds of monitoring which cannot conveniently be performed in the field, and for these a laboratory is necessary. The mobile laboratories, referred to in paragraph 8.62, may be used for detailed radiological measurements on unpackaged foods and of water that is suspected of being contaminated.

9.53. Alpha particle determination is not a matter of immediate urgency, as stated in paragraph 4.42. It is best carried out in a laboratory, in any event. Consequently, samples of soil and other materials should be collected, preferably from regions where the high intensity of gamma radiation indicates contamination from bomb residues to be considerable. These samples should then be sent to a designated laboratory for analysis.

9.54. Since radiac instruments in the field will, of necessity, be kept as simple as possible, special monitoring problems, beyond the capacity of such equipment, may arise after a contaminating atomic explosion or as the result of an RW attack. In cases of this kind, it may become necessary to refer the problems to the laboratory for solution.

PERSONNEL MONITORING

Detection of Contamination

9.55. All personnel caught in a contaminating attack, either an atomic explosion or an RW attack, should be monitored at a control point as a part of the casualty evacuation process. This is necessary for their own safety and also to prevent the spread of radioactivity from a contaminated to a clean area.

9.56. Members of reconnaissance, survey, and emergency parties, whose duties require them to enter contaminated areas, and crews engaged in decontamination operations should wear special clothing which they can discard. Nevertheless, each individual should be monitored to make sure that no radioactive material has become attached to his body. It may be suggested as a general recommendation, subject to its being consistent with the existing military situation, that no person should be allowed to enter a clean area from a contaminated one, until the monitor has verified the absence of important contamination from his clothing and body.

Measurement of Radiation Dosage

9.57. In order that a commander may take into consideration the radiation exposure as a factor in determining the present and probable future effectiveness of his men, it is necessary that he should have some knowledge of the radiation dosage which they have received. This will be true irrespective of whether the men have been exposed to the initial nuclear radiation or to the lingering radiations from the bomb residues (fission products) or from an RW agent. The immediate fighting effectiveness of individuals who have received 100 roentgens or less within a period of 12 hours will, in general, not be reduced; but some of those who have received larger doses are liable to become casualties in due course, as explained in chapter 7.

9.58. To avoid taking more risk than the situation demands, it is required to know the total radiation dose received by men entering a contaminated area on emergency missions. Monitors, in particular, are likely to be repeatedly exposed to radiation in the performance of their duties, and the dose they have themselves acquired should be determined. It is important, in this connection, that complete records should be kept of all radiation exposures.

9.59. As seen in the preceding chapter, measurement of the total radiation dose received by an individual is a form of monitoring for which various personnel dosimeters are available. The particular form to be used will depend on the purpose for which the information is required, as has been explained.

COMMAND ASPECTS

Use of Radiological Survey

9.60. As stated previously, the radiological survey of the area affected by the atomic bomb or RW attack is actually only a part of the reconnaissance which would probably be made to determine the extent and severity of the damage resulting from such an attack. It is an extension of the functions performed in a normal reconnaissance, and is made necessary by the fact that the measurement of radiation requires the use of special instruments. The primary purpose of the radiological survey is, therefore, to provide the commander with information concerning the extent and intensity of the contamination in the affected area, since this is part of the information he will require to make his general estimate of the situation. On the basis of this estimate he must determine which operations, if any, should be conducted in the contaminated area.

9.61. Since personnel exposed to sufficiently large radiation doses may become incapacitated, the com-

mander must decide how many radiological casualties he is willing to accept. Then with the aid of table 7.40 (see also fig. 7.40), which gives the expected effects on personnel of various acute doses of radiation, he should be able to assess the maximum radiation dosage that men operating in the contaminated area will be permitted to receive.

Permissible Stay Times

9.62. The next step is the determination of the allowable "stay time" of men working in the area. The monitors will have measured and reported radiation intensities in the area, which will have been corrected for decay and plotted on a map or overlay. From the plot, the commander can determine with reasonable accuracy the radiation intensity (or dose rate) at any point in the area, at any time. With this information, and the permitted radiation dose, which has been decided upon for the operation, it is possible to estimate the time of stay in the area by means of the chart in table 9.62.[3]

9.63. Suppose, for example, that the commander has decided that the urgency of a mission warrants an allowable dose of 25 roentgens, and the dose rate in the area of the operation at 2 hours after the explosion is 45 roentgens per hour. This dose rate may either be measured at the time or estimated from the radiation intensity map. The allowable dose (D) divided by the reading (R) in the area, i.e., D/R, is $25/45 = 0.55$. This result falls between two values (0.5 and 0.6) on the chart, and the lower one, i.e., 0.5, is taken. The line then is found on the chart for $D/R = 0.5$. Following this horizontally, until the column is reached corresponding to 2 hours after the detonation, the allowable stay time is seen to be 35 minutes. This means that men entering the contaminated area at 2 hours after the explosion, and staying where the radiation intensity is then 45 roentgens per hour, will receive the allowable dose of 25 roentgens in about 35 minutes.

9.64. If the stay time is too short to accomplish the desired mission, the commander must either—(*a*) revise his allowable dosage upward, or (*b*) use men in shifts, or (*c*) wait for radioactive decay to lower the radiation intensity in the area, thus permitting a longer stay time. It may be noted, in the latter connection, that at 8 hours after the detonation, the radiation intensity at the point considered above will have fallen to 8 roentgens per hour. The stay time for a dose of 25 roentgens will then be about 3 hours 49 minutes, according to the chart. It is suggested, therefore, that less urgent tasks should be delayed for as long as possible in order to take advantage of the rapid decay of the fission product activity during the first few hours (or day) after the explosion.

9.65. It must be emphasized that the chart in table 9.62 is based on the known decay rate of fission products resulting from an atomic bomb explosion and should be used *for planning purposes only*. Although the data may indicate a certain stay time, the actual time of stay will be determined at the place of operation from the dosimeters of the personnel working there, and from the instrument readings of the monitors accompanying the working party. This is necessary since the contamination pattern may be irregular, with "hot spots" in the midst of areas of lower intensity.

9.66. It should be noted, too, that the time of stay chart is not applicable where the attack has been made by RW agents. These have, in general, a much slower decay rate than the fission products resulting from a bomb explosion. Until the RW agent is identified, and its decay rate (or half life) is known, it must be assumed that the radiation intensity remains constant. The stay time is then calculated on the basis of a supposed constant dose rate as determined by a survey meter.

---

[3]For graphical methods of determining times of stay in various circumstances, see appendix II.

Table 9.62. Allowable Stay Time in Area Contaminated by Fission Products from an Atomic Bomb Explosion

D/R = Allowable dose in roentgens divided by dose rate in roentgens per hour at time of entry	Time of entry in hours after the explosion																		
	0.1	0.2	0.5	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40
0.2	1–11	0–25	0–15	0–14	0–13	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12	0–12
0.3	9–40	1–00	0–22	0–22	0–20	0–19	0–19	0–19	0–19	0–18	0–18	0–18	0–18	0–18	0–18	0–18	0–18	0–18	0–18
0.4	312–24	2–22	0–42	0–31	0–27	0–26	0–26	0–25	0–25	0–25	0–25	0–25	0–25	0–24	0–24	0–24	0–24	0–24	0–24
0.5	∞	6–12	1–02	0–42	0–35	0–34	0–32	0–32	0–32	0–31	0–31	0–31	0–31	0–31	0–31	0–30	0–30	0–30	0–30
0.6		19–20	1–26	0–54	0–44	0–41	0–39	0–39	0–38	0–38	0–38	0–37	0–37	0–37	0–37	0–37	0–37	0–36	0–36
0.7		82–06	2–05	1–08	0–52	0–49	0–47	0–46	0–45	0–45	0–44	0–44	0–44	0–44	0–43	0–43	0–43	0–43	0–42
0.8		624–48	2–56	1–23	1–02	0–57	0–54	0–53	0–52	0–51	0–51	0–51	0–50	0–50	0–49	0–49	0–49	0–49	0–49
0.9		2000–00	4–09	1–42	1–12	1–05	1–02	1–00	0–59	0–58	0–58	0–57	0–57	0–57	0–56	0–55	0–55	0–55	0–55
1.0		∞	5–56	2–03	1–23	1–14	1–10	1–08	1–06	1–05	1–05	1–04	1–04	1–03	1–02	1–02	1–02	1–01	1–01
1.25			15–30	3–13	1–54	1–38	1–31	1–28	1–25	1–24	1–23	1–22	1–21	1–20	1–19	1–18	1–17	1–17	1–16
1.5			48–20	4–57	2–30	2–05	1–54	1–49	1–45	1–43	1–41	1–40	1–39	1–37	1–36	1–34	1–33	1–33	1–32
2.0			1562–00	11–52	4–06	3–13	2–46	2–35	2–29	2–24	2–20	2–18	2–16	2–13	2–10	2–08	2–06	2–05	2–04
2.5			∞	31–00	6–26	4–28	3–48	3–28	3–16	3–08	3–03	2–59	2–55	2–51	2–46	2–45	2–40	2–38	2–36
3.0				96–39	9–54	6–09	5–01	4–28	4–10	3–58	3–49	3–43	3–38	3–30	3–24	3–17	3–14	3–11	3–08
4.0				3124–00	23–43	11–05	8–12	6–57	6–16	5–50	5–33	5–19	5–10	4–58	4–44	4–32	4–26	4–20	4–15
6.0				∞	193–19	35–35	19–48	14–43	12–19	10–55	10–02	9–24	8–57	8–19	7–46	7–15	7–01	6–48	6–34
10.0					∞	728–49	124–00	59–18	39–34	30–39	25–42	22–35	21–32	17–52	15–41	13–57	13–05	12–24	11–42

Duration of exposure (in hours and minutes) required to produce various values of D/R for various values of time of entry after the explosion

SUMMARY

Operations in a contaminated area may be facilitated by (1) surveying (or monitoring) the area for radioactivity, (2) marking contaminated regions and objects, (3) controlling operations, traffic, and personnel in the area.

A rapid radiological survey may be made from slow-flying aircraft, and this may be followed by a preliminary ground survey. These will be performed by monitors attached to normal reconnaissance and emergency parties. The preliminary monitoring will establish the general extent of the contaminated area. Subsequently, detailed surveys will determine the radiation levels of specific objects, or places, locating regions of high intensity ("hot spots"), and establishing the danger perimeter.

When a contaminated area is impassable, detailed monitoring may be carried out from low-flying aircraft. Telemeters may also be used in these circumstances. Cloud tracking should be undertaken to facilitate safe air operations after an atomic explosion, and also to indicate the possible locations of radioactive fall-out.

The radiation intensity measurements reported by monitors will be evaluated and plotted as an aid to continued operations. The contaminated area should be marked by standard and other markers. Control points should be established on access routes to control the movement of personnel, vehicles, and matériel into and out of the contaminated area.

Supplementary detailed monitoring of food and water, roads, structures, installations, and various items of equipment will be performed when opportunity permits. Monitoring of personnel caught in an attack or who enter a contaminated area is necessary, and records of radiation exposures should be kept.

Commanders will use the radiological survey information to determine the permissible stay times of personnel operating in a contaminated area.

Chapter 10

PROTECTION OF PERSONNEL

INTRODUCTION

Protection from Blast and Fire

10.01. It has been seen in chapter 7 that the injuries caused by an atomic explosion are due to the effects of blast or shock, thermal (heat) radiation, and nuclear radiation. In devising methods for the protection of personnel, all three effects must consequently be taken into consideration. While thermal radiation has the greatest casualty-producing range, actually protection against blast and nuclear radiation is in some ways the most difficult to achieve. Only massive buildings of reinforced concrete or steel-frame construction will stand up against blast and shock. But even then the roofs and interiors are liable to be damaged, and broken glass, loose objects, and debris generally will be thrown about and act as missiles.

10.02. Reinforced concrete and steel-frame structures are fire resistant, but no ordinary building is completely free from fire hazard. It is almost impossible to avoid the presence of some combustible material, and fires can start as a result of indirect effects of blast and shock. Electrical short circuits, for example, could cause a great deal of damage in the interior of a building, even though the walls remained virtually intact. Broken windows, too, may permit the entry of firebrands from adjacent, more combustible buildings.

10.03. The best protection for personnel from the blast effects accompanying an air burst would seem to be obtainable in an underground shelter of some kind. But this might not be too good if the atomic bomb were exploded beneath the earth's surface. Probably a massive concrete, underground structure would provide protection against any type of atomic explosion, with the exception of a burst in its immediate vicinity.

Protection from Thermal Radiation

10.04. Although thermal radiation can travel a considerable distance through air, it does not penetrate opaque materials. Thus, the interior of a wooden structure could provide complete shelter, as far as thermal radiation from an atomic bomb is concerned. Such a building would, of course, be extremely vulnerable to both blast and fire. In general, any structure which offers reasonable protection to individuals against blast damage would also serve as protection from the direct effects of thermal radiation. Consequently, this hazard does not need special consideration. The only requirement is that persons keep away from windows or openings through which the thermal radiations might enter.

Protection from Nuclear Radiation

10.05. Nuclear radiation differs from thermal radiation in being highly penetrating. Its intensity can, however, be diminished by passage through appreciable thicknesses of dense materials, such as steel, concrete, or soil. Of these three substances, steel, the most dense, is the most effective, for a given thickness, and soil the least effective in decreasing the radiation intensity. Wood provides even less protection than soil.

10.06. In considering protection from nuclear radiations, it is necessary to recall that the hazard may be external or internal (ch. 7). External alpha and beta particles are not ordinarily a hazard, and protection from external gamma radiation is possible. But, once a source of radioactivity has entered the body, it may remain for a considerable time and the consequences might prove serious. In a contaminated area, utmost precautions should therefore be taken to prevent entry of the radioactive bomb residues into the body, e.g., by inhalation.

SHIELDING FROM GAMMA RADIATION

Immediate Nuclear Radiation

10.07. Adequate, if not complete, shielding from external gamma radiation can be obtained by interposing a sufficient thickness of material between the individual and the source of the nuclear radiation. The effectiveness of a given material in decreasing the radiation intensity can be conveniently represented by a quantity called the "half-thickness." This is the thickness of the particular material which placed between the source of nuclear radiation and the individual will reduce the intensity of radiation reaching the individual to one-half of the original intensity.

10.08. Thus, if a person were in a position where he would receive 400 roentgens of radiation in a certain time with no shielding, the introduction of a half-thickness of any material between the individual and the source would decrease the radiation dose to 200 roentgens in the specified time. The introduction of another half-thickness would cause the person to receive only 100 roentgens in the same time. Each succeeding half-thickness decreases the radiation intensity by half, as shown in figure 10.08. One half-thickness reduces the radiation intensity to half its original value; two half-thicknesses reduce it to one-quarter; three half-thicknesses to one-eighth; four half-thicknesses to one-sixteenth, and so on.

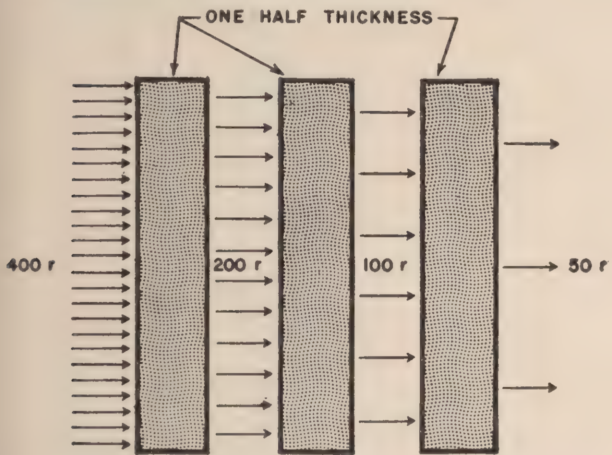


Figure 10.08. Diagrammatic representation of the "half-thickness" for gamma radiation.

10.09. The chief materials likely to be used for shielding against nuclear radiation from an atomic bomb are steel, concrete, earth, and water. The approximate half-thicknesses of these substances are given in table 10.09. The figures are not exact because the half-thicknesses depend to some extent on the type (or energy) of the gamma radiation. They apply in particular to the immediate gamma radiation emitted from the bomb at the time of the explosion. It is seen that steel of $1\frac{1}{2}$ inches thickness would reduce the radiation intensity to half, but $4\frac{1}{2}$ inches of concrete, or $7\frac{1}{2}$ inches of earth, would be required to produce the same result (fig. 10.09). Consequently, a certain thickness of steel would provide a more effective shield than the same thickness of concrete, and this would be more effective than earth. In general, the more dense the material the smaller the thickness required to decrease the gamma radiation to a certain fraction of its original intensity.

Table 10.09. Half-Thicknesses for Shielding from Immediate Gamma Radiation

Material	Half-thickness (inches)
Steel	$1\frac{1}{2}$
Concrete	$4\frac{1}{2}$
Earth	$7\frac{1}{2}$
Water	$10\frac{1}{2}$

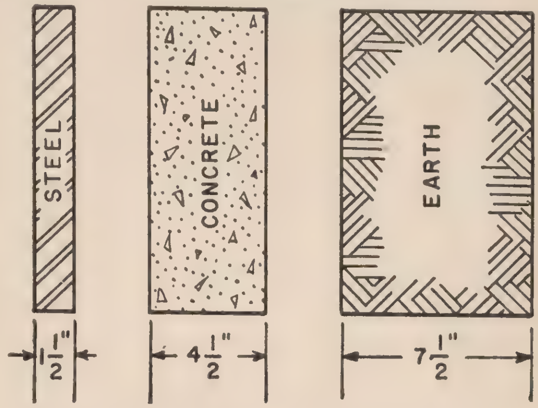


Figure 10.09. Comparison of the half-thicknesses of steel, concrete, and earth.

10.10. The thickness of steel, concrete or earth that would be necessary to decrease the immediate gamma radiation (par. 3.47) from a nominal atomic bomb detonated in the air at a height of 2,000 feet to 400, 100, and 25 roentgens, respectively, at various distances from ground zero, are represented in figure 10.10. It will be noted that, in accordance with the results given above, the scale for the thickness of earth is five times, and for concrete three times, that for steel. Some of the rounded values, for distances of $\frac{1}{2}$ mile, $\frac{3}{4}$ mile, and 1 mile from ground zero, are given in table 10.10.[1]

10.11. The various thicknesses given in figure 10.10 and in table 10.10 refer to the explosion of an atomic bomb of 20 kiloton TNT energy equivalent. For bombs of higher energy the corresponding thicknesses at the given distances would have to be increased by approximately one half-thickness of shielding material for each additional 20 kilotons of energy. It should be noted that this does not ordinarily require doubling the thicknesses of the shield-

[1]For the expected effects of different types of shielding in decreasing nuclear radiation casualties, see the chart in figure 7.40.

ing for double the bomb energy. For example, at a distance of ½ mile from ground zero, table 10.10 indicates that for a 20-kiloton bomb the amount of earth shielding required to reduce the gamma radiation to 100 r is 30 inches; whereas, for a 40-kiloton bomb the amount required would be only 37½ inches. Furthermore, as pointed out in paragraph 3.55, the *range* of the immediate nuclear radiation does not increase very rapidly with increasing energy release of the bomb. Therefore, the distances given in the first column of table 10.10 increase only slightly for larger weapons.

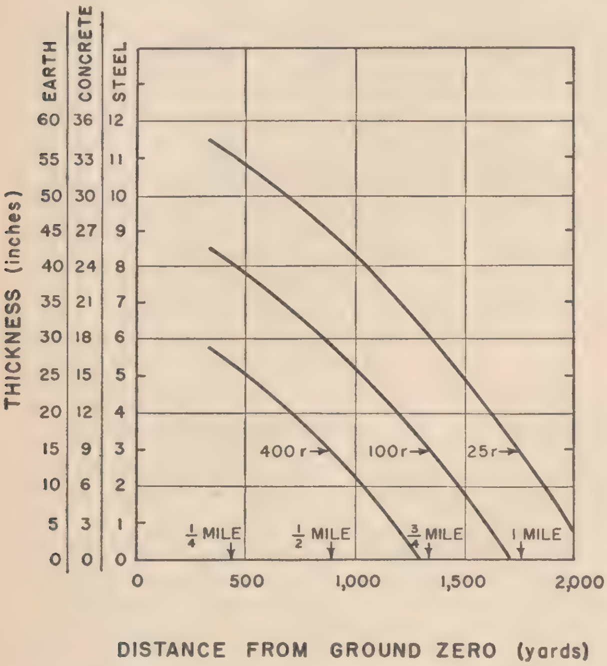


Figure 10.10. Thicknesses of steel, concrete, and earth required to reduce the immediate nuclear radiation, from the air burst at 2,000 feet of a nominal atomic bomb, to specified amounts at various distances from ground zero.

Table 10.10. Shielding from Immediate Nuclear Radiation from Air Burst of Nominal Atomic Bomb at 2,000 Feet Altitude

Distance from ground zero (miles)	Material	Thickness in inches necessary to reduce dosage to		
		400r	100r	25r
½	Steel	3	6	9
	Concrete	9	18	27
	Earth	15	30	45
¾	Steel	0	3	6
	Concrete	0	9	18
	Earth	0	15	30
1	Steel	0	0	3
	Concrete	0	0	9
	Earth	0	0	15

10.12. Since gamma radiation travels in straight lines, it might be supposed that shielding would be necessary only from the direction facing the point of the explosion. However, this is not quite true. Some of the gamma rays are "scattered," that is, turned out of their original path, by the molecules in the air. As a result, part of the radiation which would have been expected to pass completely over a shielded area will be scattered into that area, as indicated in figure 10.12a. The intensity of the scattered radiation may be something like one-tenth that of the direct radiation. To obtain complete protection from gamma radiation thus requires shielding from all directions (fig. 10.12b), even when the radiation originates at one point, such as an air burst atomic bomb.

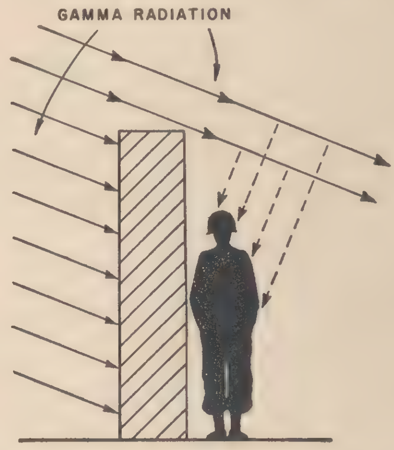


Figure 10.12a. Gamma radiation is scattered by air molecules, so that a shield in front does not provide complete protection.

Shielding from Residual Radioactivity and Base Surge

10.13. The half-thicknesses given in table 10.09 refer to the immediate gamma radiation. For the residual radiation the half-thicknesses are less, because the gamma radiations from fission products are not so penetrating as are those coming from the bomb at the instant of the explosion. However, it is impossible to make a satisfactory estimate of the amount of shielding that would be required to provide protection from the residual radioactivity. For one thing, the

radiation intensity will vary from point to point, and, for another, the dosage received will depend on the time of stay in a particular area. Nevertheless, it can be stated that the greater the amount of material surrounding an individual, the greater will be the decrease of dosage received from either residual radioactivity or base surge.

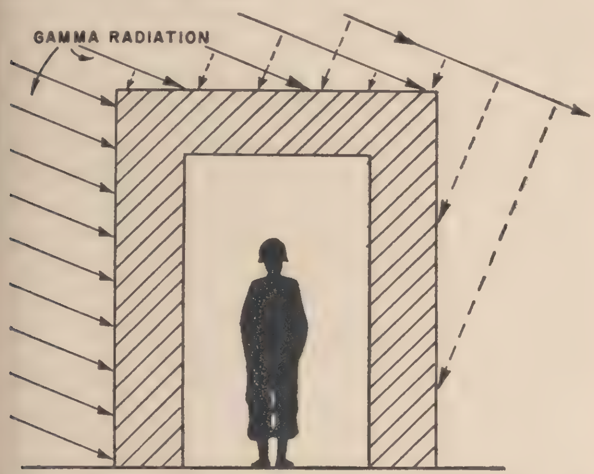


Figure 10.12b. Shielding from all directions is necessary to provide complete protection from gamma radiation.

CONTROL OF RADIATION DOSAGE

Acute and Chronic Exposure

10.14. Control of radiation dosage is an important aspect of personnel protection. If an individual has received a moderate or high dosage, he should be evacuated as soon as possible. On the other hand, if the radiation dosage is small, he can be subjected to further exposure, if necessary, without harmful consequences.

10.15. As pointed out in chapter 7, the effect on a human being of a given amount of radiation will depend on whether the dose was received in a short time, i. e., an acute exposure, or over an extended period, i. e., a chronic exposure. A certain quantity of radiation received in an acute exposure would cause more harm than the same quantity spread out in time due to chronic exposure. The longer the time over which the exposure occurs, the less the risk involved for a given total dose of radiation.

Peacetime Conditions

10.16. Although continued exposure to radiation of small intensity may not cause any obvious harmful effects within a period of weeks, months or, possibly, years, there are nevertheless undesirable changes going on in the body. Every effort should thus be made to keep both acute and chronic exposures so low that the body is capable of repairing the radiation damage as fast as it occurs. There is no doubt that the human system can do this. Every person is exposed to a certain amount of nuclear radiation, both internal and external, continually throughout life. And this is not something new; it has been going on for all time.

10.17. The human body contains appreciable amounts of radioactive carbon and potassium which emit beta particles and gamma rays. These represent a source of internal radiation. In addition, there are nuclear radiations, called cosmic rays, coming from outer space. The body is exposed to this external radiation at all times, day and night. At high altitudes, the cosmic radiation is more intense than at sea level. It is seen, therefore, that exposure to a certain amount of radiation is a normal experience to which the human body has become adapted.

10.18. In addition to this natural exposure, the peacetime occupation of certain persons, such as radiologists, X-ray technicians, and individuals who work in various atomic energy installations, subjects them to further exposure to nuclear radiations. As a result of many years of experience, it appeared that no person suffered any ill effects from exposure to radiation for long periods, provided the dosage over the whole body was kept down to 0.1 roentgen per day or less. Consequently, the peacetime permissible exposure or "tolerance[2] dose" of nuclear radiation was for many years accepted as 0.1 roentgen per day for persons who were subject to frequent exposure.

10.19. As an extreme measure of safety, the recommended permissible exposure for persons whose work brings them into daily contact with external radiation has now been reduced to 0.3 roentgen per week. Assuming 50 working weeks, this would mean a maximum of 15 roentgens per year, although every effort is made to keep the total dosage as small as possible.

---

[2] Although the term "tolerance" has frequently been used in reference to dosage of radiation, there is no proof that living tissues are actually tolerant to ionizing radiation. For this reason, the term "permissible exposure" is considered to be more accurate from a medical standpoint, and is the one which will be used in this book.

10.20. These figures refer to chronic, almost daily, exposures. If circumstances make it necessary for an individual to accept a large single (acute) dose in peacetime, it is considered that this should be not more than 25 roentgens, over the whole body. If this amount is received, then the person concerned should avoid further exposure.

Wartime Conditions

10.21. Atomic and radiological warfare may produce circumstances in which the peacetime exposures will have to be exceeded. In some cases this may be inevitable; for example, if troops in the field or ships' crews are exposed to the immediate nuclear radiation from an air burst or to the base surge and fall-out from a subsurface explosion. Personnel dosimeter readings (par. 8.33), taken at the time, will then provide a commander with information which will enable him to estimate the number of casualties to be expected. The radiation dosage in these instances will be acute, and assuming it to be absorbed over the whole body, the effects will be somewhat as given in table 7.40 and figure 7.40.

10.22. With the aid of these estimates a commander can evaluate the present and future fighting effectiveness of such of his men as have escaped mechanical and burn injuries in an atomic attack. He can then decide, on the basis of a calculated risk, whether personnel should be evacuated immediately or whether they can be kept at their duties for a period of time.

10.23. In the event of a contaminating atomic explosion or an RW attack, the situation will be complicated by the residual radioactivity. Any person who stays in a contaminated area will be continuously exposed to radiation. From the dosage received at the time of the attack, and the intensity of the residual radiation, as determined by a survey meter, a commander can make decisions concerning the evacuation of personnel. During the first day or so after the explosion, when the radioactivity is still decaying rapidly, a chart of allowable stay times such as that given in table 9.62 may be found useful for the purpose of controlling the movements of personnel. If it is necessary to occupy a contaminated area for an extended period, the exposure will be of the chronic type, and due allowance must be made for this (see table 7.48).

10.24. Another type of situation will arise when men who have not been previously exposed to radiation are required to enter a contaminated area to occupy a position, to carry out an emergency operation, or to perform some other vital mission. In these circumstances it will be difficult or impossible to keep the radiation exposure below the peacetime permissible levels. Military necessity may require individuals to accept 50, 100, or even more roentgens in one day. In every case, the amount of radiation an individual is allowed to receive before being evacuated must be a command decision. As in all military operations, the commander must take a calculated risk. He must weigh the importance of the mission or operation against the expected casualties and decide accordingly.

PROTECTIVE SHELTER

Possible Existing Shelters Ashore

10.25. In the absence of specially constructed shelters, protection from the effects of an atomic explosion can best be obtained in a foxhole, a dugout, or in the lowest floor or basement of a reinforced concrete or strong, steel-framed building. In a built-up area, the safest place is in the basement, near the walls; the next best place is on the lowest floor in an interior room, passage or hall, away from windows and, if possible, near a supporting column.

10.26. An individual in such a location would be well protected from the effects of blast and from immediate nuclear radiation, because of the intervening thickness of the walls of the building and the earth. Protection from thermal radiation would be complete. The chief hazard would be the possibility of being trapped by fire or debris, but this might be avoided if there were two or more exits.

10.27. Wooden buildings are very vulnerable to blast and fire, as seen in chapter 6; they also provide little shielding against gamma radiation. Such buildings should be avoided if at all possible. However, if the individual had no choice, it would be preferable to take shelter under a table or bed, rather than to go out into the open. Shades and blinds should be drawn, if time permits, to keep out thermal radiation and to help shield the occupants from broken window glass.

10.28. Tunnels, storm drains, and subways would provide effective shelter, unless there were a nearby underground explosion. The thickness of the earth will, in general, be sufficient to reduce the gamma radiation to harmless proportions. In addition, the structure of the tunnel, etc., will usually be strong enough to withstand blast and fire, although it may be somewhat vulnerable to underground shock.

10.29. In case of a subsurface explosion, persons taking shelter in existing buildings or structures may become exposed to residual radioactivity from contamination. Closing doors, windows, and other openings will provide some degree of safety. But, if the blast should break the doors and windows, and let in the radioactive mist or dust, this precaution will be of little value. In these circumstances, if no gas masks are available, breathing through a folded handkerchief will help to reduce the hazard.

10.30. In military installations, there often are not many buildings which are strong enough to provide effective shelter from an atomic burst. Culverts, drains, and ditches could be used in the event of an emergency, but they would offer only partial protection. Consideration should, therefore, be given to the desirability of making proper provision for sheltering personnel, in some such manner as is described below.

Shelter Afloat

10.31. Larger ships, and especially those having protective armor, can furnish excellent shelter from blast, thermal radiation, and immediate nuclear radiation effects at one-half mile or more from surface zero in the air burst of a nominal atomic bomb. Such shelter would, of course, be available only to members of the ship's company whose duties will permit them to be stationed behind shielding.

10.32. In general, the further below the main deck, the better will be the protection from nuclear radiation. Shielding is provided by armored decks, the shell plating and side armor, and by the wing water and fuel-oil tanks which form part of the antitorpedo protection. Furthermore, in the case of personnel located well below the water line, the external sea water itself offers valuable shielding against the immediate nuclear radiation. This arises because for even a fairly high air burst occurring one-half mile away, or more, the radiation will strike the ship at such an angle that it must pass through an appreciable thickness of water before entering the ship below the water line.

10.33. In the event of an underwater burst there will be no immediate radiation, but steps should be taken to prevent entry of the base surge. Consequently, all openings should be secured upon warning of an impending attack.

10.34. Unless special shielding is available, topside personnel will be exposed to both thermal and nuclear radiation, as well as to the effects of blast. In case of an air burst, self-preservation measures, to be described later, should be taken. After an underwater explosion, at not too close quarters, there may be time to obtain shelter from the base surge and water fall-out in those cases where it is not possible for the entire ship to avoid this contamination by means of maneuvering.

Specially Constructed Shelters

10.35. For personnel and services of essential importance to the functioning of a military establishment or installation, it may be considered desirable to construct special shelters. These should be built underground of reinforced concrete, perhaps 2 feet thick, and with a considerable earth cover. A structure of this kind would provide satisfactory protection, even at ground zero, from an air burst of a nominal atomic bomb at 2,000 feet. If sufficiently massive and built to withstand lateral shock, the structure could also provide protection from the effects of a nearby underground explosion.

10.36. Two aspects of specially constructed shelters require attention—these are access and air supply. Each shelter should have at least two exits, in case one caves in or is blocked by debris. The entrance passages (or ramps) should be at right angles to the shelter proper, so as to avoid direct exposure to blast, and thermal and nuclear radiations. To prevent the entry of contamination, the shelter should be airtight, except for provision made for supplying air by fans or blowers. An efficient filter should be placed in the inlet duct to remove contaminated dust particles. The Army Chemical Corps No. 6 Filter is suitable for this purpose. Because there may be a power failure in the event of an atomic attack, an

emergency supply of electricity should be available to provide lighting and to operate the ventilation system.

10.37. Where shelters are required mainly for protective purposes and not to house vital operational or control activities, much simpler methods can be used. Tunnels cut in a hillside, with entries at right angles to the main tunnel, form very effective shelters. In Nagasaki, such shelters protected persons from blast and from thermal and nuclear radiations very close to ground zero (fig. 10.37).

10.38. If the terrain is flat, several other cheap forms of shelter, which use earth as a protective medium, are possible. In the "cut-and-cover" type, a deep pit or trench is dug, and the sides are shored up with planks and wooden columns. Stout beams are placed across the excavation and upon them are laid sheets of corrugated iron. These are finally covered with a layer of earth at least 3 feet thick. The approach to the shelter is by a right-angled ramp entrance, there being two such entrances to each shelter (figs. 10.38a and b). Digging tools should be available as a further precaution against entrapment by cave-in. A shelter of this kind will provide good protection against all the effects of an air-burst nominal atomic bomb beyond one-half mile or so from ground zero.

10.39. A half-buried shelter, which is partly above and partly under ground, is similar to, but not quite so good as, the type just described. These are very simple to construct. Wood may be used for roofing in place of the corrugated sheets, but it is, of course, less permanent. A baffle of earth and boards at the entrance is desirable, to prevent direct access of blast and radiation. In Japan, half-buried shelters were made of a framework of poles, over which was placed tarpaulins; the whole was then covered with a thick layer of soil (fig. 10.39).

Figure 10.37. Tunnel shelters in hillside, very close to ground zero in Nagasaki, protected the occupants from blast, thermal radiation, and immediate nuclear radiation.

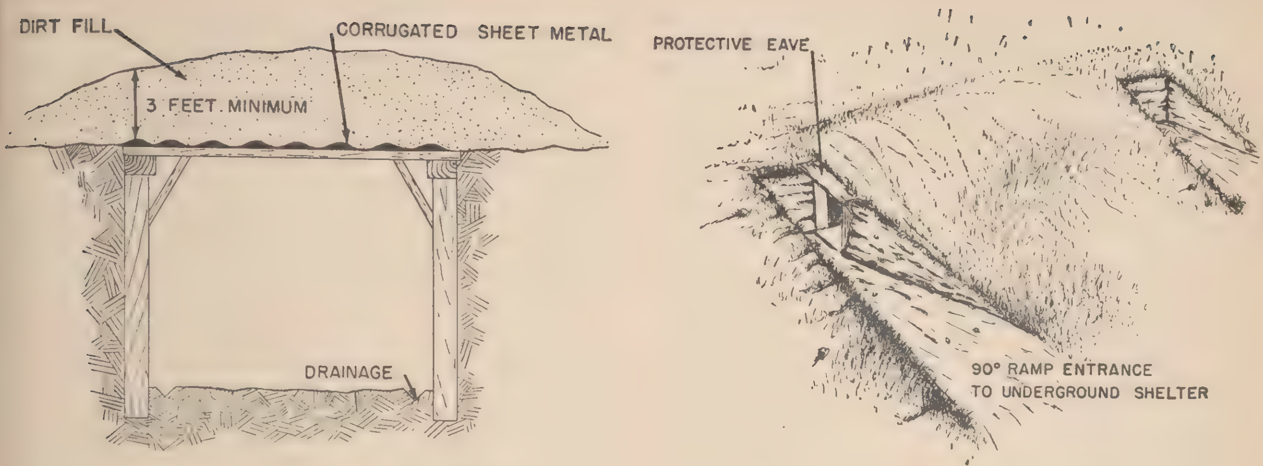


Figure 10.38a & b. Simple earth shelter suitable for a military establishment.

Figure 10.39. Simple pole and earth shelter, one mile from ground zero, undamaged by fire and blast although surrounding buildings were destroyed in the atomic bombing of Japan. (Debris was cleared from the roadways before the photograph was taken.)

10.40. In a more elaborate, and more expensive, form of the cut-and-cover shelter, a quonset hut can be placed in an excavated area and covered with earth (fig. 10.40a). Two ramp entrances, dug at right angles, would lead to the doors. A somewhat similar shelter could be made from steel culvert sections of large diameter, which are obtainable commercially. Several sections could be joined together, placed in an excavation, and an appropriate earth cover added (fig. 10.40b).

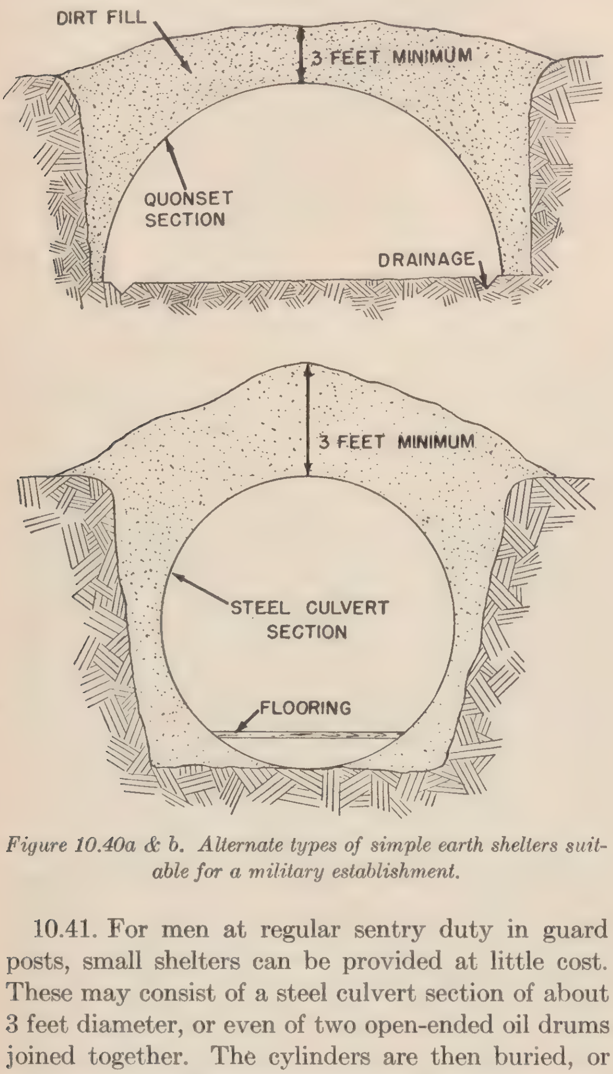


Figure 10.40a & b. Alternate types of simple earth shelters suitable for a military establishment.

10.41. For men at regular sentry duty in guard posts, small shelters can be provided at little cost. These may consist of a steel culvert section of about 3 feet diameter, or even of two open-ended oil drums joined together. The cylinders are then buried, or semiburied, with an earth cover of at least 3 feet. A ramp entrance must be provided for the completely buried shelter. One or two men lying down inside will be well protected beyond about one-half mile from ground zero in the event of an air burst.

10.42. Slit trenches and foxholes (see fig. 7.40) provide the simplest of all shelters which can be made available at military installations. Where the number of personnel is large, then more elaborate shelters are not practicable. The chief drawback to trenches and foxholes is, of course, their lack of protection from above. A high air burst at not too great a distance would send blast, heat, and nuclear radiations directly into the trench or foxhole (fig. 10.42a). The deeper the trench is dug, the greater

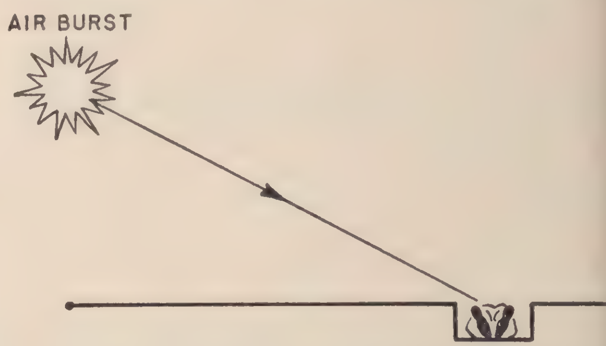


Figure 10.42a. A high air burst sends radiations (thermal and nuclear) into a small foxhole.

the protection it offers. A soldier lying, sitting, or crouching at the bottom of a deep trench can escape most of the air burst bomb's effects, even quite close to ground zero (fig. 10.42b). Trenches and foxholes would, however, be damaged by shock from nearby surface and subsurface bursts.

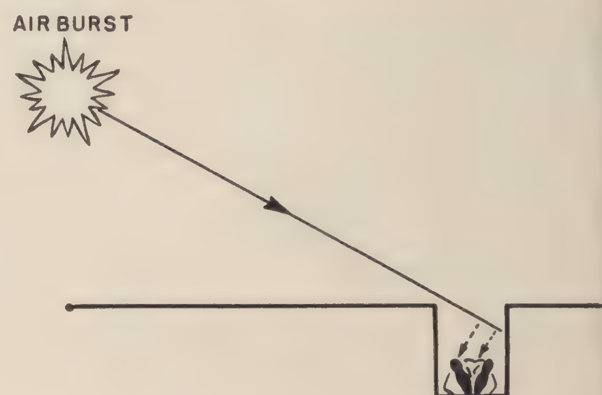


Figure 10.42b. A soldier crouching on the bottom of a moderately deep trench or foxhole is largely protected from the effects of radiation, even fairly close to ground zero. Some scattered nuclear radiation (dotted lines) may be received, but the amount will be comparatively very small.

10.43. A warning should be given in connection with the use of sandbags in the construction of earth shelters. If sufficiently close to the explosion, the burlap or other materials are likely to be scorched by the thermal radiation. The bag may then collapse and its contents will be spilled.

10.44. All the simple types of earth shelter suffer from the fact that they cannot be made airtight. It would thus be impossible to keep out radioactive contamination due to a subsurface burst. The only satisfactory way to overcome the immediate effect of this hazard would be to supply each individual with a filter mask or respirator. If this is not possible, then dust may be largely kept out by breathing through a handkerchief or a piece of cloth.

10.45. It may be possible in the field to take advantage of the terrain. A hill between an individual and the exploding bomb will almost completely cut off the thermal radiation. Although it may not entirely eliminate the effects of blast and the immediate nuclear radiation, it may well reduce them to such an extent that they are harmless.

Dispersion

10.46. An important way in which casualties in the field might be reduced is by dispersion of personnel over a large area. The figures in table 10.46 show the estimated percentages of personnel injured and killed in the open as a result of the air burst of a nominal atomic bomb, assuming them to be concentrated in circular areas of various radii about ground zero. Dispersal of troops over a large area will thus appreciably decrease the number of casualties. The data in table 10.46 are based on the assumption that the troops are in the open at the time of the explosion.[3]

Table 10.46. Estimated Effects of Dispersion of Personnel in the Open

Circular area of radius (yards)	Percent casualties		
	Killed	Injured	Total
1,500	90	10	100
2,000	51	29	80
2,500	33	36	69
3,000	23	40	63
4,000	14	28	42

[3]It should be noted that the casualty ranges given in table 10.46 are based primarily on thermal rather than nuclear radiation effects, since the limiting distance for radiation casualties would be about 1500 yards. On the other hand, if personnel are in foxholes or trenches and thereby shielded from thermal radiation, nuclear radiation becomes more significant in determining the amount of dispersion required to avoid excessive casualties (see figs. 7.24 and 7.40).

10.47. Commanders should consequently give careful consideration to the possibility of distributing personnel, and especially key personnel, as widely as possible (see par. 12.09). All operating procedures should be examined closely to determine whether unnecessarily large numbers of personnel are being concentrated in small areas during these operations. For example, dispersal of aircraft at an air base might reduce casualties to maintenance crews as well as to the planes.

10.48. Dispersal of ships, both at sea and in port, will decrease the total amount of damage and hence the casualties in an atomic explosion. Consideration should consequently be given to the matter of increasing the operating distance between ships when an attack is expected. Because of the great range of destruction resulting from an atomic burst, somewhat different defense tactics are required than in the case of HE bombs and depth charges.

Smoke Screen

10.49. If large numbers of personnel have to remain in the open and cannot take shelter, for example, in an amphibious landing, it might be desirable to employ a smoke screen as a protective device. As stated in paragraph 3.41, this would very greatly reduce the range of thermal radiation and consequently decrease the number of flash-burn injuries. On the other hand, protection from thermal radiation is so relatively simple that it is questionable whether a smoke screen would be justifiable, except in special circumstances, as indicated above. The effective use of a smoke screen is only possible if there is adequate warning of an attack. In any case, it must not be permitted to distract attention from the necessity for obtaining protection from blast and nuclear radiation effects.

INDIVIDUAL PROTECTION

Self-preservation

10.50. If there is a sufficient warning in advance of an atomic attack, the obvious step is to make for the best shelter that is available, as quickly as possible. In the case of members of the armed forces on duty, their behavior must be determined by the circum-

stances existing at the time. In general, this will be the same as those prescribed for an attack by ordinary HE bombs.

10.51. In the event of a surprise atomic explosion, certain actions can be taken by individuals which might mean escape from death or serious injury. The same applies to men on duty who cannot leave their posts. In an air burst the actions are determined by the following facts mentioned earlier in this manual. First, the thermal radiation may continue to be emitted for a second or so after the burst; second, about 50 percent of the immediate nuclear radiation is given off in the first second, and about 80 percent within 10 seconds; and third, the blast wave takes about 8 seconds to reach a distance of 2 miles, which is the approximate range of serious to moderate mechanical injury.

10.52. The first indication of an unexpected atomic air burst may be a brilliant flash of light. No matter whether in the open or inside a building, the immediate reaction should be for the person to drop to the ground, face down, at the same time trying to cover exposed portions of the skin, such as the face, neck, and hands. If this can be done within a second of seeing the bright light, some of the heat radiation may be avoided. Ducking under a table, if indoors, or into a trench or ditch, if possible, outdoors, with the face away from the light, will provide added protection.

10.53. If shelter of some kind can be reached within a second, it might be possible to miss about half of the immediate nuclear radiation. But, as stated earlier, shielding from nuclear radiation requires a considerable thickness of material, and this may not be available in the open. By dropping to the ground, some advantage may be secured from the shielding provided by terrain and surrounding structures. However, since the radiations continue to reach the earth from the atomic cloud as it rises, the protection will be only partial.

10.54. The prone position taken immediately upon seeing the light from the bomb should be held for at least 10 seconds, or longer if heavy objects are still falling. This will allow time for the blast wave to pass and thus decrease the danger from flying missiles. At a distance of 2 miles from the point of burst, 8 seconds will elapse before the sound of the explosion is heard. By this time the immediate effects will be over.

10.55. The light from a subsurface atomic explosion will not be visible for any appreciable distance, especially in the daytime. The first indication of such a burst will probably be the sensation of an earthquake-like concussion of the ground, together with the appearance of the column of water or earth. Fortunately, the thermal and nuclear radiations emitted at the time of the explosion will be absorbed by the water or the earth, respectively. However, there may still be the radiation hazard from the base surge and the fall-out.

10.56. Although the effects of blast and shock may be felt before it is fully realized that a subsurface explosion has occurred, there may still be time to obtain some shelter from the base surge and fall-out. It should be remembered that the base surge is like a fog and envelopes everything over which it passes. Adequate shelter can thus be obtained only in a closed space which the radioactive fog cannot penetrate. The fall-out, on the other hand, descends vertically (or almost so) and protection is much easier to obtain. If it is impossible to find shelter from both base surge and fall-out in a short time, then protection from the fall-out, at least, should be sought. If a filter mask is not available, a handkerchief should be held over the mouth and nose while the base surge is passing.

10.57. After a contaminating burst or an RW attack every action should be taken with the thought of minimizing the spread of the contamination. Within the contaminated area, eating, drinking, smoking, chewing gum, or any action which requires putting the hand to the mouth, must be strictly forbidden. This will help prevent entry of radioactive particles into the body. Personnel should be warned against stirring up dust and stepping into puddles. Brushing against shrubbery and trees or touching buildings and objects in the contaminated area must be avoided. These instructions should be stressed to counteract the temptation to pick up souvenirs.

10.58. The internal radiation hazard due to inhalation of radioactive particles is even greater than that due to ingestion. Realistic evaluation of the dust hazard by laboratory analyses should be made as soon as feasible. If found serious, shelter from dust

clouds raised by the wind, by aircraft propellers, by moving vehicles, etc., should be taken, if possible. Otherwise a gas mask, or handkerchief, should be used, as described above, for protection. In the case of aircraft in flight, if there is reason to believe that the plane may be in the vicinity of an atomic cloud, protection for the crew can be obtained by shutting off the ventilation or pressurization system. Further individual protection can be obtained by the use of the oxygen masks.

First Aid

10.59. As soon as the initial effects of the explosion are over, every survivor should look around to see if he can render first aid or emergency help of any kind to individuals nearby (see ch. 7). It is important to emphasize that after an air burst the administration of such help involves no special problems. The situation from this standpoint will be no different from that following an HE or incendiary attack. As indicated in paragraph 7.39, there is no danger involved in approaching or touching a person who may have received a dose of immediate nuclear radiation from an air burst.

10.60. Persons with wounds, which might permit radioactive material to enter the body, should be taken to the nearest medical station for treatment. Regardless of the indicated extent of the contamination, amputation is entirely unnecessary, in spite of statements which occasionally have been made to the contrary.

PROTECTIVE CLOTHING AND EQUIPMENT

Ordinary Clothing

10.61. Military uniforms and civilian clothing provide good protection against thermal radiation emitted at the time of an air burst. The protection is, however, supplementary rather than primary, in nature. If a person is beyond the zone of serious damage from blast and nuclear radiation, he may still be vulnerable to thermal radiation, since this has the greatest damage range. In these circumstances parts of the body that are covered by clothing will be fairly well protected from flash burns. As far as radiological effects are concerned, the chief protective value of clothing is that it keeps radioactive contamination from actual contact with the skin.

Special Clothing and Equipment

10.62. Personnel whose duties, as members of emergency and damage control teams, as decontamination crews, or as monitors, require them to enter contaminated areas or to come into contact with contaminated objects, should wear special clothing when available (fig. 10.62).[4] Such clothing normally would be issued from a control point or change station. It should be washable or expendable, and should be tightly woven or nonporous. It should cover the body completely, and should have tight connections with gloves at the wrists, and with shoes at the ankles. An overlapping connection should also exist between the clothing at the neck and a respirator or filter mask. Equipment of this kind will prevent contamination of the skin.

10.63. After each use, the clothing should be monitored.[5] Most contaminated clothing can be laundered and used again (par. 10.82). An alternative to laundering or disposal is to store the clothing to permit the radioactivity to decay. The soiled clothing is set apart in special containers and allowed to stand until its contamination has decayed sufficiently for it to be worn again.

10.64. The special clothing which should be used, if available, by personnel entering contaminated areas, can be itemized as follows:

- Any type of head covering, preferably tight-fitting.
- Goggles.
- Suitable washable and/or disposable outer garments.
- Bootees.
- Gloves, canvas type for manual labor.
- Filter masks.

10.65. Because of the possible confusion following an atomic attack, the special clothing may not be immediately available; satisfactory substitutes may be improvised as follows:

- Standard military clothing or combat fatigues.
- Clothing tightly buttoned at neck and tied at wrists and ankles with string, or stuffed into top of combat boots.

---

[4]This is sometimes referred to as "protective" clothing, although it offers virtually no protection from gamma radiation. The term "protective" may consequently be misleading in this respect.

[5]Further discussion of the monitoring of clothing will be found in the Department of Defense "*Handbook of Atomic Weapons for Medical Officers.*"

Figure 10.62. Special clothing for personnel who are required to enter contaminated areas. Outer layer of clothing—hat, shirt, pants, gloves and bootees—is designed to cover completely areas which may come in contact with contamination yet be easily decontaminated or disposed of.

Any form of gloves available.

Standard issue gas mask, if necessary.

If it becomes contaminated, the clothing should be changed as soon as practicable.

Special Clothing for Decontamination Operations

10.66. A detailed list of clothing and equipment for personnel engaged in actual decontamination operations is given in table 10.66. The various items are readily obtainable in the Armed Services. The clothing and equipment now used by the Army Chemical Corps in chemical decontamination[6] is equally useful in radioactive decontamination. Either the amphibious suit issued by the Quartermaster Corps or the Navy foulweather gear is suitable for use where water-repellent clothing is necessary. Heavy-duty clothing is not generally recommended, because it is clumsy and uncomfortable. The added safety is consequently offset by an increase in carelessness and decrease in efficiency of the wearers.

[6] "Miscellaneous Gas Protective Equipment," Department of Army Manual TM 3–290.

Table 10.66. Special Equipment and Clothing for Protection of Personnel Engaged in Radioactive Decontamination Operations

Item	Remarks
Headgear	
Protective hats or helmets	Protect against falling debris or an obstruction overhead.
Soft fatigue caps	Used in conditions where no other headgear is worn. Protects the hair.
Clothing	
Waterproof parka and trousers.	For use in wet operations and wet weather.
Heavy jackets and trousers	For use in cold weather.
Belts	
Undershirt	
Drawers	
Socks	
Coveralls (one-piece) . . .	If available, these are more satisfactory than the items listed immediately below.
Shirt	
Trousers	
Handgear	
Rubber protective gloves .	For wet operations.
Leather gloves	For handling sharp, hot debris.
Cotton or canvas gloves .	For dry operations.
Footgear	
Safety shoes (nonspark and nonskid).	Ankle high.
Rubber boots	Safety toe and lining; knee high or thigh high. For wet operations.
Bootees	Canvas, ankle high; made in two pieces—an upper and sole, to fit over shoes.
Equipment	
Goggles	For eye protection.
Respirator	For use where toxic fumes exist. Filters should be monitored after one use to see how often they should be changed.

PERSONNEL DECONTAMINATION FACILITIES

Preliminary Decontamination

10.67. After a subsurface atomic explosion, and to some extent after a surface burst, it is probable that a number of individuals will become contaminated. If a supply of uncontaminated water is available, efforts should be made to achieve partial decontamination of exposed skin surfaces by vigorous scrubbing with soap and water. Special attention should be paid to hair, nails, skin folds, etc., from which radioactive particles may be difficult to remove. Precautions should, of course, be taken to avoid abrasion of the skin.

10.68. In an emergency, if a supply of water is lacking, wiping with any clean material at hand, such as paper, straw, grass, leaves, or sand, will remove some of the radioactive contamination from the skin. But the material must be uncontaminated, or it may do more harm than good. Due care should be exercised to prevent tearing the skin, or forcing contamination into the wounds, body openings, or skin folds.

Improvised Decontamination Centers

10.69. Following the preliminary decontamination, personnel should be directed by signs or guides either to an established change station or to an improvised decontamination center. The latter are preferable if a large number of individuals have become contaminated. It should be noted that such centers or change stations are equally applicable to chemical warfare and biological warfare (CW and BW), and plans and operating procedures for any military unit should provide for their establishment.

10.70. An improvised decontamination center can be made of canvas partitions to form three sections. The first section is the undressing area. The second is the washing area, where large numbers of personnel can be rapidly washed by a spray from a simple shower or from a hose operating at reduced pressure. Portable showers, already available to the armed forces, can be used.[7] The third section provides for the issue of towels and clean clothing; the latter may be of an emergency character.

Decontamination Centers and Change Stations

10.71. The preliminary washing process may remove only about half of the contamination. Consequently, if possible, personnel will be directed to change centers, at some distance from the contaminated area, where more complete facilities for decontamination are available. Here individuals will scrub themselves with brushes, using warm water and soap. Instead of soap, household detergents, and similar cleaning agents, many of which are now available, can be used effectively. As in-

[7] "Bath Units, Field, Mobile," Department of Army Manual TM 10-1696.

dicated above, special attention should be paid to the hair and to places on the body where radioactive particles might have lodged.

10.72. After this thorough scrubbing, personnel should be monitored, with an instrument sensitive to beta particles as well as to gamma radiation (par. 8.29). If not found to be free from contamination, the washing and scrubbing process should be repeated as often as necessary. For persistent contamination, especially in wounds, cleaning under the supervision of medical personnel may be required.

10.73. On ships, personnel should be routed to special change rooms where preliminary or detailed decontamination will be performed. This will depend on the conditions and on the facilities available.

10.74. While the specific details of a final decontamination center and change station ashore may vary widely, they should all have the following basic features in common:

(1) The station must be divided into two distinct parts, a contaminated section and a clean section, with entirely separate access routes.

(2) Showers, with warm water, if possible, soap or other cleansing agents, and brushes must be provided for individual decontamination.

(3) Radiation detection (radiac) instruments, capable of detecting beta particles and gamma radiation, will be necessary for checking personnel and clothing.

(4) Supplies of clean clothing should be available.

Operation of Change Station

10.75. Change stations will be used not only for individuals who have become contaminated directly in an atomic explosion or RW attack, but also by personnel whose duties require them to work in contaminated areas or to come in contact with contaminated objects. As seen above, such persons will be supplied with special clothing. In any case, upon entering the contaminated section of the change station, personnel will be monitored. Clothing that is heavily contaminated will be either disposed of, put aside for some time for the activity to decay, or laundered, according to the extent of contamination and facilities available. Waterproof clothing should be washed down before it is taken off; it can generally be used again without further treatment.

10.76. The contaminated person will then pass on to the showers, where he will wash until cleared by a monitor. When declared to be free from contamination, he will proceed to the clean section of the change station to receive fresh clothing. A suggested arrangement of the station is indicated in figure 10.76. It uses the "clock" system, based on a circular traffic scheme, with personnel going through the station in a clockwise direction. In the figure, it will be noted that in addition to the locker room the rooms marked "Clothing Storage for Reissue," "Disposable Issue," and "Dressing Room" are indicated as CLEAN (unhatched), even though these spaces can be expected to show some evidence of minor radioactivity, due to storage and reuse of some items of clothing which may be slightly but not harmfully contaminated. However, the level of radioactivity in these rooms will be kept below that which could be hazardous from a health standpoint, and hence they may be considered "clean" for all practical purposes.

10.77. It is recommended that the "clock" system be established as standard procedure for all change stations, with such modifications as are made necessary by the specific conditions of the building or location used. Thus, any person entering a new station will know that his general path through the station should be in a clockwise direction. In any event, the separate access routes, to the clean and contaminated sections of the change station, should be clearly marked.

Change Stations on Board Ship

10.78. Personnel decontamination facilities on board ship will differ somewhat in arrangement from those ashore, but the fundamentals will be the same. The principal shipboard facility required is a shower room, either one that exists normally for bathing purposes or a suitable compartment that can be improvised rapidly for this use. On large ships several spaces throughout the ship should be considered for this contingency, since the rapid processing of many individuals may be necessary. The distance contaminated persons have to travel into the ship will also thereby be decreased.

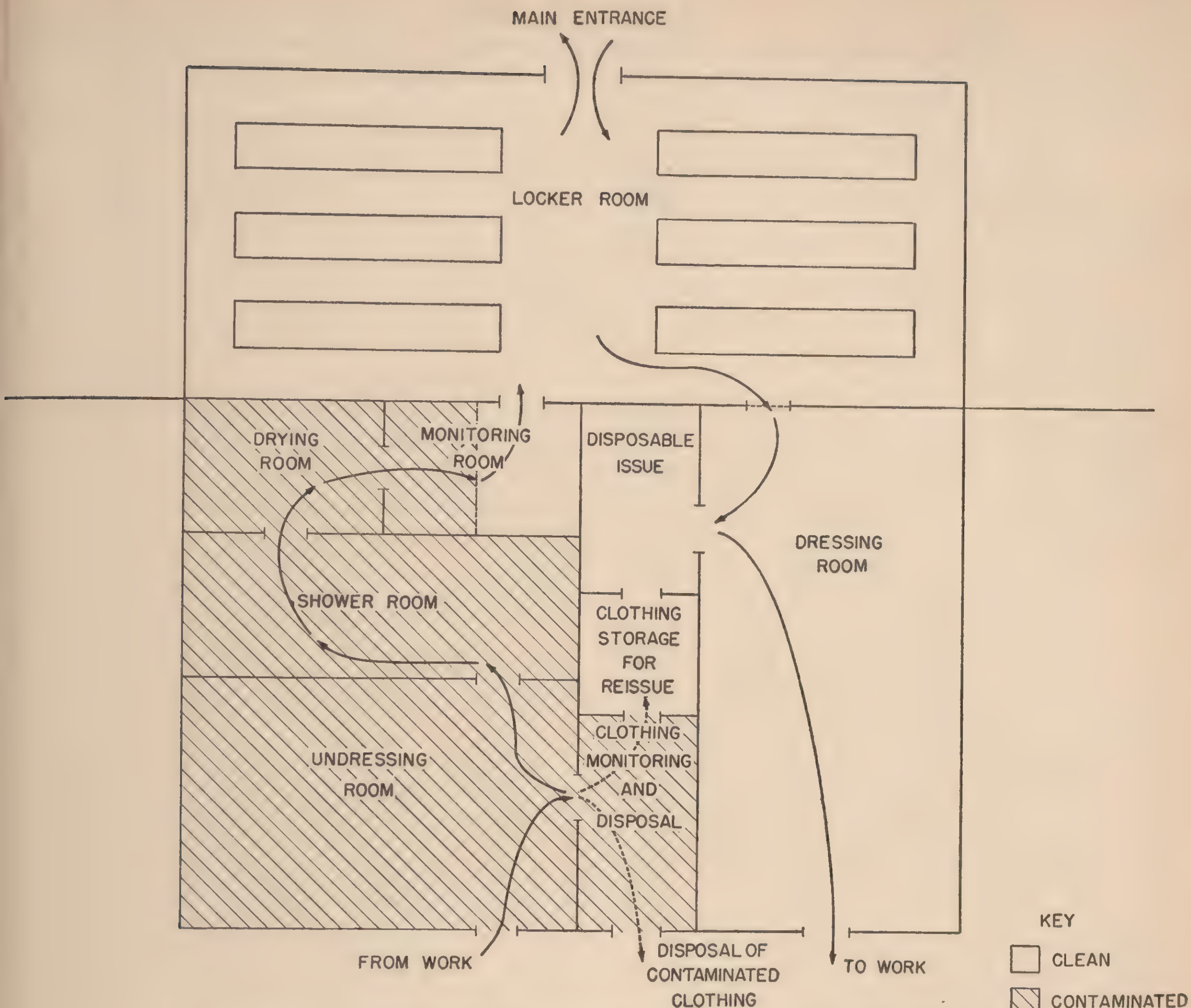


Figure 10.76. Suggested arrangement of a change station based on the "clock" system.

10.79. Every precaution should, of course, be taken to avoid bringing contamination into clean ship's spaces. Routes from weather decks to the shower stations should be planned with this in mind. If available, strips of disposable material, such as wrapping paper, canvas, sheet rubber, etc., should be used to cover walkways. As these strips become contaminated they can then be gathered up and thrown over the side.

10.80. Personnel wearing waterproof clothing should be washed down to remove exterior contamination before they leave weather decks. A temporary shower device can be rigged topside for this purpose or standard wash deck and fire hoses can be used. A compartment near the access from the deck and as close as possible to a shower room should be assigned as a contaminated undressing room. Here all contaminated personnel will leave their clothing before proceeding to the showers. After washing, with hot water and soap, individuals will be subjected to careful monitoring. A small space outside the shower room and opposite to the entrance will be required for the purpose. This personnel monitoring station constitutes the dividing line between the clean ship interior and the contaminated space which includes the access to the undressing room and the shower room.

10.81. When they have been passed by the monitor, personnel will proceed to a clean dressing room where they will dry off and be issued fresh clothing. The clean dressing and clothing issue room may or may not be adjacent to the monitor station and shower room. Any clean compartment may be used that satisfies space and stowage requirements. The main points to remember are that contaminated personnel should be kept away from the clean spaces, and that clean personnel should not return to contaminated areas, unless required to do so by their duties.

Laundry and Related Facilities

10.82. It will probably be practical to launder or dry-clean contaminated uniforms. If badly contaminated, they will either be disposed of, or stored for some time to permit the activity to decay. The special clothing issued to authorized personnel whose duties bring them into contact with contaminated areas, objects or individuals can be laundered if not too badly contaminated.

10.83. For convenience, the laundry facility[8] should be part of or near to the change station. Like the latter, it will require an ample supply of warm water and cleansing agents, and means for disposal of the contaminated water. This may be run into a pit dug in the earth and allowed to seep away. In due course, when considerable contamination has accumulated in the soil, the pit can be filled with earth, and the area roped off, if necessary.

Food and Water in Contaminated Areas

10.84. It should be emphasized that an appreciable amount of radioactivity may be detected in food and water, as measured by many portable radiac instruments now available, and they may still be acceptable for consumption, especially under emergency conditions. This is because a large proportion of the ingested fission products pass out of the body leaving only a fractional amount to act as an internal hazard.

10.85. Acceptable emergency (wartime) levels for radioactivity of drinking water, from fission products (beta and gamma) and plutonium (alpha), are given in table 10.85. It is assumed that it will be necessary to use the water for a period not exceeding 10 days. The values are expressed in terms of disintegrations per minute, per cubic centimeter of water. If the water has to be consumed for a period longer than 10 days, up to 30 days, the acceptable levels should be decreased proportionately.

Table 10.85. Acceptable Emergency Levels in Drinking Water for 10-day Consumption

Contamination	Disintegrations per minute per cubic centimeter	
	Entirely safe	Acceptable risk
Fission products	7,000	200,000
Plutonium	440	11,000

10.86. The weight of food consumed is generally less than that of water, and consequently the average radioactivity that might be allowed in food would be somewhat higher than in water. However, it may be assumed that the permissible emergency levels in table 10.85 apply to food as well as to water. Of course, if both food and water consumed concurrently are contaminated, the figures would have to be halved. Special jigs, standards and fixtures are currently under design so that it will be possible to measure these levels under standard conditions with suitable survey instruments.

10.87. The permissible activities given above are considerable in terms of the sensitivities of ordinary monitoring instruments. For example, the fission products in 30 cubic centimeters (1 ounce) of water entirely safe for 10-day consumption would give more than 10,000 counts per minute in a radiac instrument measuring only 5 percent of the radiation emitted. A preliminary monitoring with a survey meter might thus give an entirely wrong impression of the extent of contamination of food and water.

10.88. As mentioned in chapter 9, canned and many packaged goods will probably be suitable for consumption if the outer surfaces are cleaned. Surface contamination can be removed even from meats. Other exposed foods may have to be destroyed if badly contaminated.

10.89. If the local supply of water is seriously contaminated, water should be brought in from an uncontaminated source, if possible. If such a source is not available, on board ship, for example, contaminated water can be distilled carefully, and so rendered safe for drinking. It should be pointed out, in this connection, that plain boiling of water is of no value in removing contamination.

[8] "Laundry, Mobile, Two-Trailer Type," Department of the Army Manual TM 10-1680 is a suitable type.

SUMMARY

Strong structures provide the best shelter against blast, and any opaque material will protect against thermal radiation. Protection from gamma radiation requires appreciable thicknesses of material. Dense substances, such as steel, are most effective in this respect.

Under emergency conditions it might not prove possible to adhere to the strict peacetime exposure levels for radiation dosage. As in all military operations, a commanding officer must take a calculated risk based on available information.

Partial protection from an atomic attack may be obtained in existing structures, ashore and afloat. Various types of simple earth shelters, including slit trenches and foxholes, can be effective against an air burst. Dispersion, if practical, will decrease the number of casualties, and in special circumstances a smoke screen might reduce the incidence of skin burns.

An individual caught in an attack can take immediate, self-preservation measures, and after the attack he should be prepared to render first aid to others.

While special, disposable clothing is desirable for operations in a contaminated area and for decontamination work, ordinary military clothing may be adapted to provide an effective substitute. Personnel caught in a contaminating attack should be monitored and, if necessary, decontaminated as soon as possible. Emergency decontamination centers may be set up in the field. In addition, change stations should be available in a rear area or on board ship.

Food and water can appear to be appreciably radioactive as measured by many portable radiac instruments now in use and, nevertheless, may still be acceptable for consumption under emergency conditions.

Chapter 11

DECONTAMINATION

APPRAISAL OF TACTICAL SITUATION

Sources of Contamination

11.01. Radioactive contamination of areas, structures, equipment, and material may be considerable after an atomic explosion has taken place under the surface of the earth or water. Some contamination may also result from a surface burst. The base surge and fall-out may constitute a hazard as far as 3 miles or more from ground or surface zero, in the downwind direction. Up to $\frac{1}{2}$ to $\frac{3}{4}$ mile from the center of the explosion, the destruction created by blast and fire will be so great that there will be little purpose in attempting to salvage equipment or matériel. At greater distances, however, many objects will suffer less physical damage but they may nevertheless be rendered temporarily hazardous to operating personnel.

11.02. An RW attack will have similar consequences. The purpose of such an attack will frequently be to render an industrial area, military establishment, etc., temporarily uninhabitable, without destroying it (ch. 5). Structures, equipment, and so on, will thus be undamaged, although they will be so badly contaminated that they cannot be used with any degree of safety.

Recovery Measures

11.03. If equipment or structures are not badly damaged, so that they are still usable, recovery measures may be instituted, the prime objective of which is the reduction of the radiation hazard to operating personnel. In general, there are two possible types of action which may then be taken—

(1) Allowing to stand.
(2) Decontamination.

11.04. Since radioactivity decreases naturally in the course of time, the hazard to personnel will decrease correspondingly if the equipment or area is merely set aside and allowed to stand. However, this may deny the use of an important area or piece of equipment for a considerable time.

Decontamination—Tactical and Industrial

11.05. If the urgency of the military situation makes waiting impossible, an effort may be made to decontaminate the area or equipment. This involves one or more processes, which may be physical, chemical, or mechanical, whereby the contamination is removed to such an extent that the hazard to operating personnel is diminished.

11.06. There are two entirely different degrees or standards of decontamination applicable to military situations. These may be classified as follows:

(1) Rough (or tactical) decontamination.
(2) Detailed (or industrial) decontamination.

Rough Decontamination

11.07. In rough decontamination, which may have to be performed with makeshift equipment in the field, the emphasis is on urgency. The decontamination operation itself may involve some danger to personnel as far as the radiological hazard is concerned. The purpose of the rough, tactical decontamination would be merely to reduce the radiation intensity as quickly as possible to a point where personnel can use the object or remain within the area for a limited period of time.

Detailed Decontamination

11.08. Detailed decontamination, on the other hand, is a lengthy and thorough process, which is carried out at a home base or rear area. Consistent with available resources, an attempt would be made to observe peacetime, industrial radiation tolerances both for personnel engaged in the decontamination work and for those who subsequently use the equipment.

Appraisal of Urgency

11.09. The first step in a consideration of possible recovery measures after a contaminating attack is an appraisal of the urgency of the military situation. If replacements for the contaminated matériel are immediately available, there are obvious advantages in waiting for the radioactivity to decay. It involves no effort and no hazard to personnel. However, if the equipment is urgently needed, it may be necessary to attempt rough decontamination, in spite of the difficulties and risks. Detailed decontamination may be required as an intermediate possibility—it will take time, but not as long as waiting for natural decay.

11.10. Before describing the different kinds of decontamination processes in more detail, some general aspects of contamination and decontamination will be considered. These have a bearing on the problems of decontamination and will apply irrespective of whether the process is performed in the field or in a rear area.

GENERAL CONSIDERATIONS

Distribution of Contamination

11.11. No matter how the contamination originates, it will not be spread evenly. Some areas and objects will be more highly contaminated than others. Such variable factors as the depth of burst, distance from ground or surface zero, behavior of the base surge and fall-out, weather conditions, character of the terrain, and nature of the exposed materials, will all have some effect. Wind may carry the contaminated particles for a considerable distance before they reach the earth. Rain, on the other hand, may cause them to fall nearer to the center of the explosion, or further away, according to circumstances. With wet contamination, rough and porous objects will be more seriously contaminated than those which have smooth surfaces, and contamination will tend to collect in cracks and crevices.

11.12. The radioactive material from the fall-out will be deposited mainly on the exteriors of buildings, ships, equipment, etc. But the base surge, if formed, may spread into the interiors. In any event, contamination will not necessarily stay on the outside. It may be carried inside a building or other structure by the wind, by water, or through ventilation systems.

11.13. Careless movement of men and vehicles also will spread the radioactive material. Persons walking from a contaminated area into a clean area will carry contamination with them on their clothing, shoes, and other equipment. Vehicles can spread contamination from one place to another in various ways; for example, by raising radioactive dust particles which may find their way into uncontaminated buildings.

Types of Contamination

11.14. Variable conditions not only determine where the radioactive particles will land; they also affect the tenacity with which activity clings to the surface. In the simplest case, the radioactive material merely rests on the surface, being retained only by the force of gravity. Such particles are, of course, easy to remove. In other cases, strong forces acting between atoms or molecules result in the particles being held much more firmly. This is referred to as "*ad*sorption." Removal of adsorbed contamination is still possible but more difficult.

11.15. A third condition arises with porous or fibrous materials, such as rope, canvas, unpainted wood, concrete, etc. Contaminated fog, liquid, or dust can penetrate the surface openings and so carry radioactive particles into the interior of the material. Contamination is then by "*ab*sorption," and decontamination is very difficult.

11.16. Even where particles of contaminant remain on the surface, they may, in the course of time, enter into chemical combination with the atoms or molecules of the contaminated material. The compounds so formed, similar in character to rust on iron, are firmly attached to the surface and decontamination becomes a difficult problem.

11.17. It should be noted that although neutron-induced activity (par. 3.60) is, in a sense, a form of contamination, it differs from that due to the base surge or fall-out in the respect that it is not merely confined to the surface of the material in question. Consequently it is a waste of effort to attempt to decontaminate articles containing sodium or copper if there is reason to believe the radioactivity has been caused by neutrons. The simplest solution is to put the objects aside and allow the activity to decay naturally.

General Aspects of Decontamination

11.18. It will be clear from the foregoing statements that in undertaking a decontamination operation there are many facts to be considered. The variation in type, degree, and extent of contamination may mean that a method of decontamination which will work well in one location may be ineffective in another. Those responsible for decontamination must decide upon and carry out the best procedures for eliminating the contamination hazard without impairing the utility of the object while, at the same time, keeping the radiation exposure of operating crews down to safe levels.

11.19. Another aspect of decontamination which must be emphasized is that no decontamination process can either neutralize or destroy the radioactivity. All that can be done is to remove the source of the radiations from a particular structure or object, and transfer it elsewhere where it does no harm. Therefore great care must be taken to make sure that the contamination is not merely spread from one place to another, where it is equally hazardous. The disposal of material removed in a decontamination operation, and the movement of men and vehicles must be given constant consideration.

11.20. The degree to which decontamination is carried will depend on circumstances, and on the time available. A bridge, for example, needed for truck traffic would not require intensive decontamination, because personnel crossing it would be exposed to radiation for only a short time. On the other hand, if engineers have to spend several hours on repairs to this bridge, the decontamination would have to be much more thorough before it could be regarded as radiologically safe.

Protection of Decontamination Crews

11.21. Men engaged in decontamination work should wear special clothing, as described in paragraph 10.66 and table 10.66. Such clothing should cover as much of the body as possible and have a minimum number of openings through which radioactive material might penetrate. While the clothing will not stop gamma radiation, it will keep the contaminating material away from the skin. Coveralls, preferably one-piece, canvas bootees, and cotton or canvas work gloves are suggested for dry operations. For wet operations, however, water-repellent clothing, rubber boots, and rubber gloves are desirable. Goggles and a filter mask will be required where contaminated dust may be encountered, and headgear which will prevent contamination from getting into the hair. In an emergency field situation, where special clothing is not available, the substitutes referred to in paragraph 10.65 should be used. If possible, some kind of waterproof clothing should be included.

11.22. In addition to special clothing as partial protection against radioactive material reaching the skin, workers need protection from excessive exposure to radiation. Each operator will consequently carry a personnel dosimeter (par. 8.33) to record his total radiation exposure. A monitor, equipped with a survey meter and self-reading dosimeter, should accompany the decontaminating crew. He will keep a check on the radiation dosage received by personnel and also determine the effectiveness of the decontamination operation. Where the radiation intensity is high, the control agency can protect workers by rotating them among jobs of various degrees of radiation hazard.

ROUGH (TACTICAL) DECONTAMINATION

General Methods

11.23. As indicated earlier, rough decontamination is essentially a field operation in which speed is the main consideration. It will be employed only in cases of military necessity. The simplest materials and equipment, perhaps of a makeshift and rough-and-ready character, may have to be used. The work will be performed under far from ideal conditions to meet a tactical situation in the field. It would be unrealistic to attempt to carry the decontamination to such a degree that the radiation intensities would be acceptable for long-term peacetime operation or occupation. All that is required is that temporary use of a piece of equipment or occupation of a structure will not constitute a serious hazard to personnel.

11.24. Rough decontamination will usually be applied to such objects as ships, vehicles, tanks, aircraft, and guns. A good example of an urgent situation in which rapid, if rough, decontamination may be required is that of a ship at sea, which has been contaminated as the result of an underwater burst. The decontamination would be carried only far enough to permit personnel to remain on the ship for accomplishment of its immediate military mission, or until it reaches a repair base. In general, however, such large-scale, tactical decontamination would not be undertaken unless, as in the case of a ship, there is no military alternative. The rough decontamination of the other items mentioned above is, of course, a less formidable task.

11.25. The most practical method for rough decontamination is by water washing. Either fresh water or salt water may be employed for the purpose. The use of a stream of water from a hose will make it

unnecessary for operating personnel to approach the contaminated object too closely. If greasy surfaces, of a vehicle for example, are to be decontaminated, the addition of soap or other detergent, if available, would greatly increase the efficiency of the process. Provision should be made for the disposal of the run-off water in those cases where it might subsequently prove harmful to personnel.

11.26. Rough decontamination of land areas may be performed by bulldozers, patrol graders, or similar power equipment, as described more fully below. Such equipment provides a certain amount of protection for the operators against the radiation from the debris. Since the use of motorized equipment may raise considerable quantities of radioactive dust, the area should be moistened with water fog (fig. 11.26). The interior of a building into which radioactive dust has entered may be roughly decontaminated by vacuum cleaning.

Rough Decontamination and Natural Decay

11.27. Although natural decay has been considered earlier as an alternative to decontamination, it is important to bear in mind that the two are not mutually exclusive. The activity of the fission products decays rapidly during the first few hours after an atomic explosion. Consequently, if the tactical situation were such that the contaminated article could be allowed to stand for a few hours, the decontamination problem would be decreased. Personnel could then approach the object more closely or remain in its vicinity for a longer time. However, after the first day or so following the explosion there is relatively little to be gained by waiting, unless the period could be extended very considerably, e.g., to a month or a year, or so.

11.28. The advantage to be derived from natural decay would not apply to the same extent in the event of contamination by an RW agent. If the latter were a single substance or a simple mixture, the rate of decrease of its activity would depend on the half life. Even if this were as short as a week, it would mean that it would require a delay of a week for the activity to decrease to half of its original value. Whether such a delay is worth while or not would be determined by the existing circumstances.

Rough Decontamination of Roadways and Land Areas

11.29. After a contaminating attack, it will be necessary to clear roadways and other access routes as rapidly as possible. This may be required for the passage of troops and for the use of rescue and emergency teams. The quickest method for clearing a road littered with contaminated debris or of opening up a way through a contaminated land area is by means of a bulldozer. In the former case, the bulldozer will push the debris into piles or windrows along the side of the road, while in the latter, the top few inches of contaminated earth will be moved to the side in a similar manner.

11.30. The farther the contaminated material is pushed away from the road or cleared path, the less the radiation hazard to personnel using the route. Some indication of the decrease in radiation intensity on a narrow road or path as the result of clearing strips of various widths on each side is given in table 11.30. Thus, by having an additional strip of 5 yards cleared on each side, the radiation intensity on the road is decreased by 50 percent.

Table 11.30. Decrease in Radiation Intensity by Widening a Narrow Road

Width of strip (yards)	Radiation intensity decrease (percent)
5	50
10	63
15	70
20	75

11.31. If the route is to be used for relatively fast vehicular traffic only, the degree of decontamination need not be as great as if it were to be used by foot troops. This factor would have to be taken into consideration in assessing the width of the path to be bulldozed. A final decision would be based on monitoring with radiac survey instruments.

11.32. After clearing the wreckage by bulldozer, paved roads should be hosed down with water, if available, to wash loose radioactive material from the surface. The streams of water should be aimed so that they achieve maximum erosive action without endangering the operator. Work should proceed from clear into contaminated areas, and from high to low points. If it is found necessary to work uphill, means, such

Figure 11.26. Use of water fog to reduce radioactive dust hazard.

as an earth dam across the road, should be provided to channel the water into the drainage system.

11.33. It is very important when hosing to make certain that waste water drains away to a place where it is not a hazard. For this reason drainage should be prepared before a road is hosed down. The most expedient way to dispose of the waste water is through the regular storm drains or sanitary system. However, it is necessary to make sure that the drainage system is not blocked. If a clear drain cannot be found, water may be run into pits and allowed to seep away.

11.34. Large, unsurfaced ground areas are difficult to decontaminate. A bulldozer can clear a path that will permit rapid transit across the area; the contaminated earth is then merely pushed aside. But if the whole space has to be occupied or used in some way, the problem becomes serious. As a general rule, the contamination will be found in the top few inches of earth, and the only really satisfactory treatment is to scrape off this layer by means of a bulldozer. The earth so removed must be disposed of in some manner, and this may not be a simple matter.

11.35. In most cases, the best that can be done is to clear the most important areas with a bulldozer, while in adjacent areas the top layer of earth is only turned under—by plowing, for example. By turning under the top layer, which contains virtually all the contamination, the radiation intensity at the surface will be appreciably cut down. At the same time, the hazard from contaminated dust will be decreased. It should be recalled, in this connection, that before performing any operation with earth, it should be wetted down so as to reduce the dust hazard.

Rough Decontamination of Ships

11.36. When contamination of a ship is restricted to its weather decks, it will frequently be possible to effect decontamination at sea, to an extent sufficient to permit the vessel to continue operating for some time. By reducing the radiation intensity, members of the crew will be able to stay at their stations without incurring too great a risk. Under any given conditions, it will be the commanding officer's responsibility to decide if, and to what extent, decontamination should be undertaken while the ship is still at sea.

11.37. The first step in the decontamination procedure is a vigorous hosing down with sea water. The purpose of this is to clear contamination, as rapidly as possible, from large topside areas, and particularly those that will require manning if the ship is to return to action. If feasible, work will proceed from less to more contaminated regions, from higher to lower surfaces, and from bow to stern. Everything possible should be done to prevent contaminated water from flowing back over cleaner areas. In particular, it must be kept out of ship interiors, vent systems, doors, hatches, etc. Fortunately, disposal of the waste presents no serious problem, for it can be allowed to run over the side where it is rendered essentially harmless by dilution with large quantities of sea water.

11.38. Hosing down will be most effective if metal or painted surfaces have not been permitted to dry after the contamination has been deposited. Studies have shown that a very effective way of preventing contamination is to allow clean water to wash over ship surfaces just prior to the contaminating action. The surfaces are then hosed down as soon as possible after the action, and before they have dried. Experiments are under way to determine the feasibility of installing devices which will permit the decks to be wetted by remote control at the time of a contaminating attack.

11.39. After the preliminary decontamination with water, some freedom of movement topside will be possible. Consideration will then be given to the more complete decontamination of such areas and equipment as are essential for the continued, even if temporary, operation of the ship. In selecting the procedure to be adopted in each case, the following points should be borne in mind: (1) the method should be capable of rapid action, so as to keep the radiation exposure of personnel to a minimum; (2) it should be suitable for the material to be decontaminated, usually painted steel; (3) it should not require large quantities of special materials or dangerous chemicals; and (4) it should make use, as far as possible, of equipment, services, and materials which already exist on ships.

11.40. Next to water, the most convenient decontaminating agent on a ship will be steam, especially in conjunction with a detergent (fig. 11.40). Its action is very rapid and the rate of surface coverage is high. It can be used without harm on finished metal surfaces, such as gun mechanisms, and it is particularly effective in removing greasy and oily films upon which contaminants have been deposited. Commercial, steam-jet cleaning equipment may be available for decontamination purposes on board ship.

11.41. Caustic solution, such as lye or boiler compound, can be used for badly contaminated painted surfaces. The solution may be applied with a steam-jet cleaning apparatus when its efficiency will be enhanced by the higher temperature. After being softened by the caustic, the layers of paint are washed off or removed by scrapers. A hot solution of trisodium phosphate acts rapidly as a paint cleaner. It has the advantage of being suitable for hand-wiping techniques in places difficult of access or on equipment that requires careful treatment. It can also be applied with a steam-jet apparatus, the softened paint surfaces being afterwards removed by hosing or scraping.

11.42. It should be understood that the decontamination methods described above, carried out at sea, are not intended to be complete. Their purpose is merely to reduce the radiation intensity as quickly as possible and to such an extent that it will not be a serious hazard to the ship's crew for the short period required for the completion of an urgent mission, or for return to port. As soon as feasible, the vessel should undergo more thorough decontamination at an appropriate shipyard or advance base.

Figure 11.40. Use of steam for decontamination. The operator should wear waterproof clothing that will completely cover him and a respirator to prevent inhalation of loosened contaminated material.

Rough Decontamination of Aircraft

11.43. The treatment of aircraft, as of ships, will depend upon the extent of damage and upon whether the contamination is exterior only or whether it is both exterior and interior. An undamaged plane, for example, may become contaminated only on its exterior surfaces, at an airfield or on an aircraft carrier, provided the plane is closed and the engines are not running. In cases of this kind, a rapid tactical decontamination may reduce the activity sufficiently to permit operation of the craft.

11.44. After as much delay as the circumstances permit, to take advantage of natural decay of the radioactivity, the contaminated aircraft should be washed down thoroughly with water. Regular fire hose, equipped with fog or spray nozzles, will be satisfactory. If these special nozzles are not available the water pressure must be reduced so that the planes are not damaged. In some instances a sprinkling system can be used. The addition of soap or other detergent to the water would be an advantage, as it would help to remove contamination attached to greasy or oily surfaces. Precautions for the disposal of contaminated waste water must, of course, be taken here, as always.

11.45. As far as land-based aircraft are concerned, this is probably as much as can be done at a forward base. Consequently, after hosing down, the aircraft should be monitored to determine the extent of decontamination. If this is not sufficient to permit operation without undue hazard to the crew, the decontamination process should be repeated, and time allowed for natural decay to reduce the radiation hazard to an operationally acceptable level.

11.46. On an aircraft carrier it may be possible to proceed further with the decontamination by the

use of steam jets, preferably with the addition of a detergent. Monitoring will indicate the areas where considerable contamination is still present and these can be given special treatment.

11.47. Where the degree of external contamination is beyond the capacity of the immediately available facilities, or where there is internal contamination of the plane and engine, time will have to be allowed for the radiation intensity to decay to an operationally acceptable level. The engines should present no hazard except to maintenance personnel. However, it is believed that by taking suitable precautions, work could be safely performed on the engines after a few days.

11.48. If a plane has flown through the atomic cloud, or if the engine has been running during the transit of the base surge, decontamination will be very difficult. The exterior of the airframe and engines should be washed thoroughly with water and detergent. While the aircraft may then have been decontaminated to an acceptable operational level, the engine may still constitute a hazard to maintenance crews. In this event, the engine should be appropriately tagged, so that the proper precautions are taken when maintenance is required. Certain parts, such as supercharger compressor sections, carburetor, and exhaust stacks may be found to be too radioactive to work on. If so, they should be removed as rapidly as possible and replacements used.

Rough Decontamination of Tanks, Trucks, and Heavy Weapons

11.49. In a tactical situation, the quickest way of decontaminating tanks, trucks, and heavy weapons would be by water washing, preferably with a high-pressure hose. The addition of a detergent will facilitate decontamination of greasy surfaces. If steam is available, its use may be very effectively combined with that of a detergent. It is expected that in many cases these procedures will reduce the contamination to an extent that is acceptable in an emergency.

DETAILED (INDUSTRIAL) DECONTAMINATION

Decontamination Procedures

11.50. Detailed or industrial decontamination will be carried out, as time and facilities permit, generally in rear areas or at repair bases. It might involve the use of a variety of equipment and chemical reagents. The main purpose would be thoroughness of the recovery process. Detailed decontamination would be carried out in such a manner as to approach as closely as possible the strict industrial peacetime standards of radiation exposure. In any case, and consistent with the means available, the contamination would be reduced to such an extent that the equipment would represent a minimum of radiological hazard to personnel operating it for long periods of time.

11.51. Three basic procedures are employed in decontamination operations:

(1) Surface decontamination.
(2) Aging and sealing.
(3) Disposal.

Each of these methods has a unique purpose, and one can be used to supplement another. Surface decontamination reduces the contamination without destroying the utility of the object. In aging and sealing, the activity is allowed to decrease by natural decay, and the residual contamination is then sealed on to the surface. Finally, in disposal operations, contaminated debris and articles which are either badly damaged or which cannot be decontaminated, e.g., porous materials, are removed.

Surface Decontamination

11.52. Because radioactive contamination is essentially a surface phenomenon, it will generally yield to surface cleaning or surface removal methods. Ordinary cleaning methods leave a small residue on the surface, and this may still be a health hazard. Consequently, the work must be performed with a high degree of efficiency. Since radioactivity can be neither neutralized nor destroyed, it may cause recontamination after its removal from the original surface. It is therefore necessary to control the radioactive material all the way from its original location to the point of final disposal.

Aging and Sealing

11.53. This may be the most practical method for areas and equipment which are not needed immediately. Since the intensity of beta and gamma radiation falls off rapidly with time, the external radiation hazard is greatly reduced within a few days. While

the alpha activity does not decrease appreciably, the particles have little penetrating power. However, there is some danger from the residual contamination (alpha and beta) as a result of inhalation and ingestion, and all that is necessary is to prevent the radioactive material from getting into the body. Consequently, satisfactory decontamination can be achieved by waiting until the gamma radiations are down to a relatively safe level ("aging"), and then coating the surfaces to seal in the residual contamination ("sealing").

11.54. In the sealing technique, common materials such as asphalt, paint, plastic, and grout (a thin cement mixture) can be used. Because of its simplicity, the method is suitable for large-scale operations on open-ground areas, roadways, buildings, and vehicles that are not required urgently. The sealing could be performed just as well before the aging, since the gamma activity would decay in any event. But this makes it necessary to remain in the contaminated area to carry out the sealing process. It is thus better to allow the area or object to age first, before starting to seal.

Disposal

11.55. Surface decontamination, and aging and sealing can solve many contamination problems. But contamination which covers large areas will complicate operations. For example, many structures and machines may require more attention than their utility warrants.

11.56. Objects which are badly damaged and also highly contaminated will not be worth decontaminating. Porous material may defy surface decontamination. Delicate equipment may not withstand the rough cleaning methods or may not be adaptable to sealing techniques. In these cases, disposal may be a more practical solution.

11.57. If it is decided for reasons of military or economic necessity, that a contaminated area must be cleared, structures and equipment which are difficult or impossible to decontaminate must be disposed of in some manner. However, large-scale disposal of material in such an area is a laborious process and will be undertaken only when it is essential to reoccupy the area on a continuous basis.

11.58. There are, in general, two ways to dispose of radioactively contaminated material—

(1) The material is collected, concentrated if possible, and then removed to a storage area away from people.

(2) The contamination is dispersed or diluted in an inactive medium, such as the atmosphere or large bodies of water, to the extent that a hazard no longer exists.

Advance Precautions

11.59. Although any contamination problem can be handled, in principle, by one or more of the three methods referred to above, it cannot be denied that detailed decontamination is always difficult. In many cases the problems could be simplified by advance planning. The susceptibility of installations and equipment to contamination can often be decreased by proper design and treatment. For example, coating porous and irregular surfaces with a nonporous material, such as paint, will not only make serious contamination less likely, but it will make decontamination less difficult. The cost of any such preparations should be balanced against the military value of the equipment and the likelihood of its becoming contaminated.

Methods of Detailed Surface Decontamination

11.60. The success of surface decontamination depends primarily upon the suitability of the methods employed. An unsuitable method may only aggravate the contamination problem, or may even destroy the utility of the object. To reduce the radiation level efficiently and without injuring the object unduly, the characteristics of both the surface and the method should be understood. If the uses and limitations of the various decontamination methods are appreciated, no situation will prove altogether impossible, although a great deal of time and labor may be consumed in the process of recovery.

11.61. The general procedures which appear to be suitable for detailed decontamination operations are summarized in table 11.61, which indicates the materials and situations, for which each process is best suited. The most practicable methods for installations and equipment are those utilizing vacuum cleaning, water, steam, detergents, complexing

agents; organic solvents, inorganic acids, organic acids and mixtures, caustics, abrasion or flame cleaning. The first three—that is, vacuum cleaning, water, and steam—remove only the loosely held contamination. Methods employing detergents or complexing agents may succeed in removing the tightly bound contamination, but the agents will not attack the surface material to an appreciable extent. The last four methods, namely, those involving organic solvents, acids, caustics, abrasion, and flame cleaning, remove the outer layers of the surface material along with the contamination.

11.62. As a general rule, except for porous or very greasy surfaces, water washing or steam with detergents, will be used first. This may remove up to 90 percent of the contamination. The remainder can then be attacked with acids, complexing agents, organic solvents, etc., according to which appears to be most advisable in the circumstances. For porous substances, dry methods, e.g., abrasion or flame cleaning, are most suitable.

11.63. The tables at the end of this chapter (pp. 172 to 178) give a comprehensive summary of the essential characteristics of the methods used for detailed decontamination. The procedures are first classified according to the surface to be treated, and then according to the agent or method.[1]

Aging and Sealing

11.64. As stated earlier, aging and sealing procedures are primarily designed to prevent dispersion by fixing residual contamination to the surface. In many instances, these procedures avoid difficulties inherent in surface decontamination or disposal operations. The greatest advantage is that they present no disposal problems. There is no need to provide permanent storage facilities.

11.65. The use of aging and sealing procedures is determined, to a large extent, by whether tactical considerations will permit a period of aging before recovery of the object. The waiting or aging period is necessary to allow the intensity of the gamma radiations to decrease by means of natural decay, since the sealing materials will not form an effective shield

[1] For further details of decontamination methods see "Decontamination" U. S. Naval Radiological Defense Laboratory Report AD-206(Y); "Shipyard Industrial Radiological Manual," Bureau of Ships, Navy Department, NavShips-250-348.

Table 11.61. Materials and Situations for Which Various Decontamination Procedures are Best Suited

Agent or method	Materials	Situations
Vacuum cleaning	Dry surfaces . . .	Where contamination is in form of dust. Interiors of buildings and vehicles.
Water	Nonporous surfaces (metal, paint, plastic, etc.).	Decontamination from a distance. Fixed or movable items.
Steam	Painted or oiled, nonporous surfaces.	Rooms where contaminated spray can be controlled. Buildings, vehicles, aircraft and ships.
Detergents . .	Nonporous surfaces (metal, paint, plastic, etc.). Industrial films, oils and greases.	Surfaces covered with atmospheric dust and grease. Fixed or movable items.
Complexing agents.	Metal or painted surfaces.	Large, unweathered surfaces. Surfaces where corrosion is not tolerable. As an adjunct to water or steam treatment.
Organic solvents	Painted or greased surfaces.	Final detail cleaning. Where complete immersion dipping operations are possible. Movable items.
Inorganic (mineral) acids.	Metal or painted surfaces, especially those exhibiting porous deposits, e. g., rust, marine growth, etc.	Decontamination of pipe circulating systems. Dipping of movable items.
Organic acids and mixtures.	Metal and painted surfaces.	Large surfaces. Both fixed and movable items.
Caustics . . .	Painted surfaces .	Large surfaces. Dipping of painted objects.
Abrasion . . .	Metal and painted surfaces.	Large, weathered surfaces. Fixed or movable items.
Flame cleaning	Unpainted concrete and wood; corroded metal surfaces.	Floors, roads, structures requiring repainting.

against these radiations. The waiting period can be shortened, however, by using some method of rough decontamination to remove part of the contamination—for example, by hosing the surface.

Sealing Materials and Applications

11.66. A good sealing material should–

(1) Have good adhering qualities, i.e., not crack or flake off the surface.
(2) Be chemically inert—not enter into chemical reaction with atmospheric elements.
(3) Be nonporous and waterproof to prevent the diffusion of the contamination through the sealer to the surface.
(4) Dry or set within a few hours after application under standard conditions.
(5) Have wear-resistance qualities so that the danger of seal breakage is minimized.
(6) Be heat resistant within the range of temperature to be expected on the particular surface.
(7) Be adaptable to fast application techniques, e.g., spraying.

11.67. These characteristics have varying degrees of importance, depending upon the conditions to which the surface is subjected. Long-wearing characteristics might be a prime consideration in choosing a sealing material for a roadway, while ease of application might be the deciding factor in choosing a sealer for large vertical surfaces.

11.68. The best available procedures and materials for the most common types of surfaces are outlined in table 11.68. Further information will be found in the summary at the end of the chapter, and in the references given in paragraph 11.63.

Table 11.68. Situations and Techniques for Which Various Sealers are Best Suited

Sealer	Situation	Technique
Asphalt and asphalt concrete.	Roadways and large land areas.	Standard road resurfacing operations
Paints and plastics.	Vertical and overhead surfaces.	Standard spray operations
	Vehicles and equipment.	
Grout	Concrete surfaces .	Gunite spraying process

Disposal—Concentration

11.69. In the event that it is found necessary to dispose of contaminated structures and materials, as indicated in paragraph 11.57, the first step would be an attempt to reduce the bulk of the material. This should be done by mechanical demolition or wrecking in such a way as to avoid the spread of contaminated dust, and to involve a minimum of handling by personnel. In these operations, material should be continuously monitored, as an appreciable quantity may not be contaminated. Material which appears to be uncontaminated should be put aside where it can be rechecked for activity. If cleared, it can be stockpiled for reuse or disposed of in a routine fashion. The result of such demolition would be the orderly segregation of contaminated material, concentrated as much as possible under the circumstances.

11.70. Additional methods of concentration of the contamination vary with the physical characteristics of the material. Contamination from combustibles, such as wood, vegetation, clothing, oils, etc., is best concentrated by a controlled burning process. Precautions must be taken to prevent the escape of the radioactive smoke and ash, if possible. At least it should not be allowed to blow directly into an inhabited area. In open country, dilution by the atmosphere would greatly reduce the hazard.

11.71. Fusible materials—e.g., metal, plastic, glass, etc.; and inert materials—e.g., stone, brick, tile, concrete, etc.; after concentration by demolition and sorting may require disposal without any additional concentration.

11.72. The end result of decontamination operations and concentration processes is a large quantity of radioactive waste that must be moved to permanent storage sites. Even under favorable circumstances, transportation of radioactive wastes is hazardous. As a consequence, waste material should be handled in such a manner that maximum personnel protection is provided and contamination of new areas is prevented.

11.73. The strict rules governing the packaging and handling of radioactive materials under peacetime conditions would not be practical when handling large amounts of radioactive waste. Certain procedures can be proposed, however, for emergency wartime conditions. The radioactive dust hazard can be

substantially reduced by keeping the waste material in a moistened condition, especially during loading and unloading, when the danger of stirring up dust is greatest. Radioactive ash waste presents a serious control problem. In addition to wetting down the ash, it may be advisable to package the material.

Methods of Disposal

11.74. In general, there are three methods of disposal of radioactive materials—

(1) Burial on land.
(2) Entombment.
(3) Burial at sea.

The following descriptions show how they should be used for either temporary or permanent storage.

11.75. Burial on land is best adapted to areas which are remote from the sea and have no entombment sites—e.g., caves, mines, etc., in the vicinity. For permanent burial, a cell lined with concrete is recommended. It should be waterproofed with grout or similar material, to prevent seepage and possible contamination of water supplies. When filled, the cell should be covered with at least 6 feet of earth. Its position should be marked on the ground and reported through military command channels as a map overlay.

11.76. Disposal by entombment is a simplified burial method which can be used if there are abandoned or low-grade mines, or natural caves nearby. The storage site should be as high as possible to provide a dry atmosphere. The entrance of the mine or cave should be sealed and its position marked and reported, as mentioned in the preceding paragraph.

11.77. For burial at sea, a deep water site should be chosen, preferably where there are no strong currents. The contaminated material may be placed in drums or caissons, which should be strong and reasonably leak-proof. Containers should be completely filled with water if necessary. If proper precautions are taken, there will be no appreciable escape until the radioactivity has become insignificant. Further information on disposal will be found in the references given in paragraph 11.63.

SUMMARY OF METHODS FOR REMOVAL OF CONTAMINATION

In the following charts are summarized the essential features of the various methods for the removal of contamination referred to in this chapter, under the headings of: Surface Decontamination; Sealing; Disposal.

The methods of surface decontamination are tabulated in two ways:

(1) *According to the type of surface to be decontaminated.* For each type of surface the methods are given in the general order of the increasing severity of action on the surface. While a severe action is generally the most effective in removing the contamination, the future utility of the surface may require the use of a milder method of decontamination.

(2) *According to the method of decontamination.* In this table, the various procedures are also given roughly in order of increasing severity of action on the surface.

Summary of Surface Decontamination Methods—by Type of Surface

Surfaces	Decontaminating agent	Action	Technique	Advantages	Disadvantages
Paint.	Water from high pressure sources.	Dissolving and erosive action.	Work from high to low areas to minimize recontamination. In addition, spraying should be from upwind side of object to avoid contaminated spray.	Most practicable method for gross decontamination from a distance. Contamination reduced by approximately 50%.	Protection needed from contaminated spray. Runoff must be controlled. Should not be used on a surface covered with contaminated dust.
	Steam (with detergent, if available).	Dissolving and erosive action.	Same as for water . . .	Most practicable method for decontaminating large horizontal, vertical, and overhead surfaces. Contamination reduced by approximately 90%.	Same as for water.
	Soapless detergents.	Emulsifying action on greasy surfaces.	Apply hot solution by standard wiping technique (one minute rub). Concentration should be sufficient to produce suds.	Reduces activity to tolerance in one or two applications.	Mild action.
	Complexing agents: Oxalates. Carbonates. Citrates.	Forms soluble complexes with contaminated material.	Solution should contain 3% (by weight) of agent. Spray on surface and keep moist for 30 minutes by periodic spraying with solution. After allotted time, flush material off with water.	Holds contamination in solution. Contamination (unweathered surfaces) reduced by approximately 75% in 4 minutes. Easily stored, nontoxic, noncorrosive.	Requires application from 5 to 30 minutes for effectiveness. Has little penetrating power; hence of small value on weathered surfaces.
	Trisodium phosphate.	Grease and paint cutter.	Rub surface 1 minute with rag moistened with hot, 10% solution. Do not allow solution to drip. Wipe dry with a second rag. Use clean rag surface for each application.	Reduces activity to tolerance in one or two applications. Good method for vertical and overhead surfaces.	Hand application method slow and laborious. Must not be used on painted aluminum or magnesium.
	Organic solvents (industrial stripping compounds).	Grease and paint remover.	Entire surface may be immersed in solvent. Solvent may also be applied by standard wiping technique for detail paint removal.	Quick dissolving action makes solvents useful on vertical and overhead surfaces.	Requires good ventilation and fire precautions.
	Caustics (sodium, calcium, or potassium hydroxide).	Paint remover.	Let paint mixture remain on surface for 2 hours, then wash off with high pressure stream of water. Remove remaining paint with long-handled scrapers and use a dilute acid rinse.	Minimum contact with contaminated surface. Contamination reduced almost 100%.	Applicable only on horizontal surfaces. Personal hazard. Not to be used on aluminum or magnesium.

Summary of Surface Decontamination Methods—by Type of Surface (continued)

Surfaces	Decontaminating agent	Action	Technique	Advantages	Disadvantages
Paint—continued	Wet sand-blasting.	Abrasion . . .	Standard technique. Follow up with vacuum treatment to concentrate contaminated abrasive.	Complete removal of surface and contamination. Feasible for large-scale operations.	Contaminated sand spread over large area. Method too harsh for many surfaces.
Metal .	Water	Dissolving and erosive action.	(*See* Painted surfaces.)	Contamination reduced by approximately 50%.	(*See* Painted surfaces.)
	Detergents . . .	Emulsifying action.	(*See* Painted surfaces.)	Removal of oil or grease films.	(*See* Painted surfaces.)
	Organic solvents.	Dissolving power.	(*See* Painted surfaces.)	Stripping of grease . .	(*See* Painted surfaces.)
	Complexing agents: Oxalates. Carbonates. Citrates.	Forms soluble complexes with contaminated material.	Spray 3% solution of agent on surface and keep moist for 30 minutes by periodic spraying with water. Afterwards, agent should be flushed off.	Holds contamination in solution.	Good only on horizontal surfaces. Limited value on weathered surfaces.
	Inorganic acids (hydrochloric and sulfuric).	Dissolving power with respect to metals and porous deposits.	Allow acid solution (9–18% hydrochloric or 3–6% sulfuric) to react on weathered surface for 1 hour. In circulatory systems, from 2–4 hours. Acid should be neutralized with mild alkali and surface flushed with water.	Fast, complete decontamination.	Good ventilation required, for acid fumes toxic to personnel. Possibility of excessive corrosion. Acid mixture cannot be safely heated.
	Acid mixtures. .	Dissolving action.	(*See* Inorganic acids above.) Mixture: 0.1 gallon hydrochloric, 0.2 lb. sodium acetate, 1.0 gallon water.	Action of weak acid. Reduces contamination on unweathered surfaces.	(*See* Inorganic acids.)
	Hand abrasion (buffers, grinders).	Abrasion . . .	The surface should be kept in a moistened condition to minimize the airborne contamination.	Useful for detail cleaning.	Impractical on porous surfaces. Follow-up procedure required to pick up powdered contamination.
	Wet sand-blasting.	Abrasion	(*See* Painted surfaces.)	(*See* Painted surfaces.)	(*See* Painted surfaces.)
Brick and concrete	Vacuum blasting.	Abrasion	Conventional technique. Hold tool flush to prevent escape of contamination.	Direct removal of contaminated dust.	Contamination of equipment.
	Vacuum cleaning (vapor dust trap).	Vacuum suction of dry particles.	Conventional technique. Use special filter to prevent escape of contamination through exhaust.	Direct removal of contaminated dust.	Contamination of equipment.

Summary of Surface Decontamination Methods—by Type of Surface (continued)

Surfaces	Decontaminating agent	Action	Technique	Advantages	Disadvantages
Brick and concrete—continued	Flame cleaning .	Chars or scorches the surface.	Determine appropriate depth of surface charring experimentally by adjusting flame temperature and duration of exposure. Follow charring with gentle abrasion. Remove loose scorched or charred material by vacuuming.	Only method of trapping contamination on surface.	Slow and painstaking. Airborne hazard is great. Requires ventilation hood.
Asphalt	Wet scrubbing with mechanical streetsweepers.	Abrasion . . .	Wet scrubbing technique, followed by flushing with water.	No direct contact with surface; contamination may be reduced to tolerance.	Residual contamination fixed into asphalt. If road is subject to further contamination, may require respraying.
Tile. .	Trisodium phosphate.	Dissolving action.	Scrub hot 10% solution into surface and flush thoroughly with water.	Simplicity of method .	Deteriorating effect upon tile.
Wood .	Floor chippers, grinders, and planers.	Removal of top wood.	Conventional techniques. Protect personnel against dust hazard.	Complete removal of contamination.	Dust hazard. Cannot use moisture.
	Flame cleaning .	Chars or scorches the surface.	Determine appropriate depth of surface charring experimentally by adjusting flame temperature and duration of exposure. Follow charring with gentle abrasion. Remove loose scorched or charred material by vacuuming.	Only method of trapping contamination on surface.	Slow and painstaking. Airborne hazard is great. Requires ventilation hood.
Soil . .	Land scrapers and bulldozers.	Removal of top soil.	Keep soil damp but not soaked before operations.	Complete decontamination possible.	Constant decontamination of equipment required. Disposal of large amounts of soil required.

Summary of Surface Decontamination Methods—by Method

Method	Surfaces	Action	Technique	Advantages	Disadvantages
Vacuum cleaning	Dry contaminated surfaces.	Removal of contaminated dust by suction.	Use conventional vacuum technique with efficient filter.	Good on dry porous surfaces—avoids water reactions.	All dust must be filtered out of exhaust. Machine is contaminated.
Water	All nonporous surfaces (metal, paint, plastic, etc.). *Not suitable for porous materials* such as wood, concrete, canvas, etc.	Solution and erosion.	Use gross decontamination employing water shot from high pressure hoses. Work from top to bottom to avoid recontamination; and from upwind to avoid spray. 15 to 20 feet from the surfaces is the optimum operating distance. Vertical surface should be hosed at an incident angle of 30 to 45 degrees. Determine cleaning rate experimentally if possible. Otherwise, use a rate of 4 square feet per minute.	All water equipment may be utilized. Allows operation to be carried out from a distance. Contamination may be reduced by approximately 50%. Water solutions of other decontaminating agents may utilize water equipment.	Drainage must be controlled. Porous materials will absorb contaminants. Oiled surfaces cannot be decontaminated. Not applicable on dry contaminated surfaces (use vacuum). Spray will be contaminated.
Steam	Nonporous surfaces (especially painted or oiled surfaces).	Solution and erosion.	Work from top to bottom and from upwind. Clean surfaces at a rate of 4 feet per minute. The cleaning efficiency of steam may be greatly increased by using detergents.	Steam reduces contamination by approximately 90% on painted surfaces.	Steam subject to same limitations as water. Spray hazard makes the wearing of waterproof outfits necessary.
Detergents . .	Nonporous surfaces (especially industrial film)	Emulsifying agent. Wetting agent.	Rub surface one minute and wipe with dry rag. Use clean surface of the rag for each application. A powdered rotary brush (with pressure feed) is more efficient. Moist application is all that is desired. Solution should not be allowed to drip on to other surfaces. Solution may be applied from a distance with a pressure proportioner.	Dissolves industrial film which holds contamination. Contamination may be reduced by approximately 90%.	May require contact with surface. Mild method not efficient on long-standing contamination.
Complexing agents: Oxalates. Carbonates. Citrates.	Nonporous surfaces (especially unweathered surfaces, i.e., no rust or calcareous growth).	Forms soluble complexes with contaminated material.	Solution should contain 3% (by weight) of agent. Spray surface with solution. Keep surface moist for 30 minutes by spraying with solution periodically. After allotted time, flush material off with water. Agents may be used on vertical and overhead surfaces by employing mechanical foam.	Holds contamination in solution. Contamination (unweathered surfaces) reduced by approximately 75% in 4 minutes. Easily stored, nontoxic, noncorrosive.	Requires application from 5 to 30 minutes. Little penetrating power; of small value on weathered surfaces.

Summary of Surface Decontamination Methods—by Method (continued)

Method	Surfaces	Action	Technique	Advantages	Disadvantages
Organic solvents	Nonporous surfaces (greasy or waxed surfaces, or paint or plastic finishes, etc.).	Solution of organic materials (oil, paint, etc.).	Entire unit may be immersed in solvent. Also may be applied by standard wiping procedures (*see* Detergents).	Quick dissolving action. Recovery of solvent possible by distillation.	Requires good ventilation and fire precautions. Toxic to personnel. Material bulky.
Inorganic acids: Hydrochloric. Sulfuric.	Metal surfaces especially those with porous deposits (i.e., rust or calcareous growth). Circulatory pipe systems.	Strong dissolving power on metals and porous deposits.	Dip bath technique is advisable for movable items. Acid should be kept at a concentration of from 1 to 2 normal (9–18% hydrochloric, 3–6% sulfuric acid). Reaction time on weathered surfaces should be 1 hour. Pipe systems, 2 to 4 hours. Afterwards, surface should be neutralized and rinsed.	Corrosive action on metal and porous deposits. Corrosive action may be moderated, if necessary, by addition of corrosion inhibitors to solution.	Good ventilation required because of toxicity and explosive gases. Acid mixtures should not be heated. Possibility of excessive corrosion if used without inhibitors. Sulfuric acid not effective on calcareous deposits.
Acid mixtures: Hydrochloric, or Sulfuric—with Acetates or with Citrates. Acetic acid. Citric acid.	Nonporous surfaces (especially those having porous deposits). Circulatory pipe systems.	Dissolving action.	Applied in same manner as inorganic acids. Mixture consists of: 0.1 gallon hydrochloric, 0.2 lb. sodium acetate, 1.0 gallon of water.	Dissolving action may reduce contamination by approximately 90% in 1 hour (unweathered surfaces).	Weathered surfaces may require prolonged treatment.
Caustics: Lye (sodium hydroxide). Calcium hydroxide. Potassium hydroxide.	Painted surfaces (horizontal).	Dissolving power softens paint (harsh method).	Lye paint-removal mixture: 10 gal. water, 4 lb. lye, 6 lb. boiler compound, 0.75 lb. cornstarch. Allow lye paint-remover solution to remain on surface until paint is softened to the point where it may be washed off with water. Remove remaining paint with long-handled scrapers.	Minimum contact with contaminated surfaces. Easily stored.	Personnel danger (painful burns). Reaction slow; thus, is not efficient on vertical surfaces or overheads. Should not be used on aluminum or magnesium. Method difficult on vertical or overhead surfaces.
Trisodium phosphate.	Painted surfaces (vertical, overhead).	Dissolving power (mild method).	Hot 10% solution applied by standard wiping technique (*see* Detergents). One-minute rub.	Reduces activity to tolerance in one or two applications.	Destructive effect on paint. Not to be used on aluminum or magnesium.

Summary of Surface Decontamination Methods—by Method (continued)

Method	Surfaces	Action	Technique	Advantages	Disadvantages
Abrasion: Scraping, grinding, buffing, etc.	Nonporous surfaces.	Surface removal.	Use conventional procedures, but keep surface damp to avoid dust hazard.	Activity may be reduced to as low a level as may be desired.	Impracticable for porous surfaces because of penetrations by moisture.
Wet sandblasting.	Nonporous surfaces.	Surface removal.	Wet sandblasting is most practical on large surface areas. Collect used abrasive.	Fast	Contamination spread over area must be recovered.
Vacuum blasting.	Porous and nonporous surfaces.	Abrasion with controlled removal by vacuum suction.	Hold tool flush to surface to prevent escape of contamination.	Controlled disposal.	Contamination of equipment.
Flame cleaning	Unpainted concrete or wood.	Chars or scorches the surface.	Determine appropriate depth of surface charring experimentally by adjusting flame temperature and duration of exposure. Follow charring with gentle abrasion. Remove loose scorched or charred material by vacuuming.	Only method of trapping contamination on surface.	Slow and painstaking. Airborne hazard is great. Requires ventilation hood.

Summary of Sealing Methods

Sealing material	Technique	Best suited for
Asphalt and asphalt concrete .	Use road resurfacing equipment. Spraying with hot asphalt is rapid, but the seal will last a few months at most. For more permanent seal, use asphalt concrete.	Roadways and land areas.
Paints and plastics	Use conventional spraying equipment. Vehicles and other mobile equipment first should be partially decontaminated by hosing. Periodic inspection of seal desirable.	Large vertical and overhead surfaces. Vehicles and equipment.
Grout (thin mixture of sand, cement, and water).	Use Gunite spray process. Layer of grout at least 1/4 inch thick provides a permanent seal.	Concrete surfaces.

Summary of Disposal Methods

Phase	Method	Technique	Best suited for
Concentration	Demolition	Use cutting torches and standard wrecking equipment. When possible, handle by remote control. Use minimum number of personnel. Keep material in a moistened condition to reduce dust hazard.	Combustible, inert, and fusible material.
	Segregation	Monitor material and separate contaminated items from uncontaminated. Clean material to be stockpiled for reuse. Disadvantages are great bulk and airborne hazard.	Inert and fusible material.
	Controlled burning.	Use an incinerator which will adequately control the fly ash. Ashes to be monitored and disposed of as concentrated noncombustible material. Bulk is reduced to about 1% of original. Must use filter to reduce airborne hazard.	Combustible material.
Storage	Burial on land.	For temporary storage: As close to area of contamination as practicable. Make use of natural depressions. Avoid locations having heavy runoff of water. Clay substrata is preferable; if possible, avoid substrata composed of sand or rock. Seek site with low water table. Additional requirements for permanent storage: Have solid footing. Burial cell should be (1) lined with concrete (2) waterproofed, (3) filled to within 6 ft. of surface only, (4) filled with earth, (5) capped with concrete roof and sealed, (6) covered adequately with earth. Core drills or wells should be placed alongside to provide for periodic inspection.	Geophysical areas which are remote from sea with no natural entombment sites.
	Entombment	Material should be placed as high as possible in the mine or cave to provide a dry atmosphere. The material should be placed in leakproof containers or the tomb suitably sealed to prevent leaching of the radioactive material into the ground. Containers should be treated to prevent corrosion. Entrance to tomb should be blocked off.	Land areas presenting natural entombment sites.
	Burial at sea.	Material should be placed in reasonably strong and leakproof containers, preferably of concrete. These should be completely filled (by adding water if necessary), sealed, and then sunk in deep water (preferably 1,000 fathoms or more).	Areas close to large bodies of water.

SUMMARY

After a contaminating attack, recovery of equipment may be achieved either by waiting, to permit the radioactivity to decay, or by decontamination, which reduces the activity to a level when it is no longer a significant hazard to operating personnel. Decontamination may be either rough (tactical) or detailed (industrial). The recovery procedure adopted will be a command decision and will depend on the urgency of the military situation.

Rough decontamination is essentially a field operation in which urgency is the main factor. Its purpose is to reduce contamination sufficiently to permit personnel to work with, or close to, equipment for limited periods. Rough decontamination of ships, tanks, vehicles, aircraft, and guns may be achieved by means of water, or steam if available.

Detailed decontamination, in which the emphasis is on thoroughness, will be carried out in rear areas and repair bases. Three main procedures can be used—(1) surface decontamination, (2) aging and sealing, (3) disposal.

The purpose of surface decontamination is to remove contamination without impairing the utility of the object. The variety of surfaces calls for the use of a number of different methods, such as those employing vacuum cleaning, water, steam, detergents, complexing agents, organic solvents, acids, caustics, abrasion, or flame cleaning.

Sealing is undertaken after the gamma activity has been reduced to a considerable extent by natural decay (aging). The residual contamination is then sealed in so that it will not become an internal hazard. Asphalt, paints, plastics, and grout are the most practical sealing materials.

If it is necessary to dispose of large quantities of radioactive materials, they should first be concentrated in some manner to reduce their bulk. The waste material can then be buried on land, entombed in a mine or cave, or buried at sea.

Chapter 12

EMERGENCY CONTROL MEASURES

INTRODUCTION

Purpose of Emergency Control

12.01. The over-all effects of an atomic attack, as regards both damage to structures and equipment and injuries to personnel, can be diminished and recovery greatly facilitated by suitable emergency control measures. To be effective such measures must be initiated immediately after an atomic explosion, and because of the confusion that will exist at the time, they will require careful and detailed planning and preparation well in advance. It is the purpose of the present chapter to show how the information given and techniques described in the preceding chapters can be used to minimize the effects of an atomic attack, and to speed rehabilitation.

Main Situations of Atomic Attack

12.02. There are three main situations, in which atomic weapons might be used and in which emergency control action would be necessary.

(1) *Forward elements of military forces in the field in contact with the enemy; a naval task force approaching an enemy fleet or coast line; a forward air base engaged in tactical support of a ground operation.* In these cases, the commander's primary military mission must continue to be accomplished and it may not be possible immediately to divert any considerable force to relieve the effects of the atomic attack.

(2) *The communication zone, advance naval bases, and airfields used for strategic purposes.* These may be near cities or ports because of the communications network and the proximity of depots and supply centers. A similar situation would arise if atomic weapons were used tactically against an enemy, and U.S. forces found it necessary subsequently to bring the effects under control, in connection with follow-up operations.

(3) *Military installations of various kinds within the continental United States.* These are frequently located near large, urban and industrial areas. Such installations may belong to any of the three Services.

12.03. While other situations may arise, it is seen from the foregoing that in many instances, especially where military commanders are in a position to take emergency control measures, their commands will be adjacent to, or surrounded by, civilian communities. In such cases, the military will probably have to cooperate with civil authorities to control, as rapidly as possible, the effects of an attack by either atomic or conventional weapons. In some circumstances, the military commander may even find it necessary to take complete control of the situation.

12.04. In any event, a military installation may be largely dependent on a nearby city for transportation, communications, and supply. Recovery of vital facilities in the city is thus necessary to the maintenance of the installation. It is essential, therefore, that members of the Armed Services should be prepared both to act for their own defense, and to cooperate with the civil defense organization.

12.05. The considerations of emergency control measures in this chapter will be divided into three main sections, dealing with situations on land, at sea, and in the air. It should be noted that, in accordance with the foregoing remarks, all Services will be concerned with the situation on land, especially as they affect a built-up area, i.e., an urban or industrial complex.

EMERGENCY CONTROL ON LAND—FORWARD AREAS

Field Situation

12.06. In the field, there is little a military commander can do, in the event of an impending atomic attack, that he would not do in any case. The effects of an atomic air burst on ground forces, in the attack or in a defensive position, would be similar in many respects to those of saturation bombing, and the measures taken would be comparable. As seen in previous chapters, by taking cover in moderately deep foxholes or trenches, considerable protection can be achieved from the effects of blast, thermal radiation, and the immediate nuclear radiation. When it is found that any appreciable radioactive contamination exists, a plot showing the extent and degree of the radiological hazard (fig. 9.30a) will be helpful to the commander in making tactical and other command decisions.

12.07. In the case of a contaminating burst or an RW attack, it would be desirable, consistent with the military mission to be accomplished, that survivors should be evacuated as rapidly as possible and processed through a personnel decontamination center. As seen in chapter 11, contaminated equipment need not be abandoned. If they are urgently required and a supply of water is available, tanks, vehicles, aircraft, and guns can be given a rough decontamination which will permit their use for limited periods, at least, without undue hazard to personnel. While this tactical decontamination under field conditions may present difficulties, it may be well worth while in an emergency.

12.08. If troops in the field have been exposed to a substantial amount of nuclear radiation, either immediate or residual, the commanding officer should be prepared for the possibility of delayed casualties (ch. 7). Although the combat effectiveness of the exposed troops may not be greatly affected at the time of the attack, they may require replacements within a few days.

Dispersion in the Field and Rear Areas

12.09. An important doctrine of defense, especially applicable to atomic bombing, is not to present a remunerative target. Dispersion is a possible way of meeting this requirement. Troops in combat formation generally have adequate dispersion to minimize losses. Additional dispersion should be sought only if it does not interfere with tactical operations. For example, whenever possible reserves should be dispersed by battalion or comparable units so that one atomic bomb will not destroy more than one battalion.

12.10. The targets generally presented by command and logistical installations in rear areas can be made less remunerative to the enemy either by making the installations smaller in size or by dispersion of activities within installations. Dispersion by means of reduction in size of each installation would require an increase in the total number of such installations, which generally is not acceptable as it would tend to increase the operating personnel requirements. However, dispersion of the activities of an installation within the same general area, without changing their size, may still be adopted to reduce the potential damage from a single atomic burst. Figures 12.10 a and b illustrate the number of such activities that might be affected by one atomic burst, depending upon whether or not they had been properly dispersed.

12.11. Another method of rendering a logistical installation a less remunerative target would be to reduce the levels of supply. This might be accomplished without loss of operating efficiency if combat troops could practice supply economy more rigidly, and supply agencies could reduce the handling and delivery time by improved operating and planning procedures.

Protection of Transportation Facilities

12.12. In general, railroads, highways, pipe lines and power lines present linear rather than area targets. Even if damaged or destroyed at one point, this can readily be repaired or bypassed (par. 6.79) so that operations are not seriously affected. Consequently, few desirable targets exist on these arteries, except at major junctions or defiles. Defensive measures which may be taken prior to an attack would be to bypass junctions and defiles by shunt-line railroads, highways, and pipe lines. Pipe lines and power lines should be laid out as a network to minimize the loss of individual substations, breaks in the line, or destruction of specific terminals.

12.13. A speed-up in handling and delivery of supplies will reduce the quantities in transit at any one time. In addition, it will tend to decrease the bulk storage facilities in rear areas. In ports, for example, petroleum products might be delivered from off-shore anchorage by floating pipe lines directly into the main pipe-line network. The concentration of transportation facilities at the dockside, as well as the dockside installations and storage requirements, would be reduced by loading directly from ship to trucks, utilizing shipboard gear.

12.14. If rail transport is used at the port, vulnerability to atomic attack is increased, since loading direct from ship to freight cars is difficult. Transfer to rail cars requires dockside cranes and large numbers of personnel. A shuttle system from ship by truck to dispersed rail sidings is a possible solution, where hauls from port to destination are too long for direct truckage.

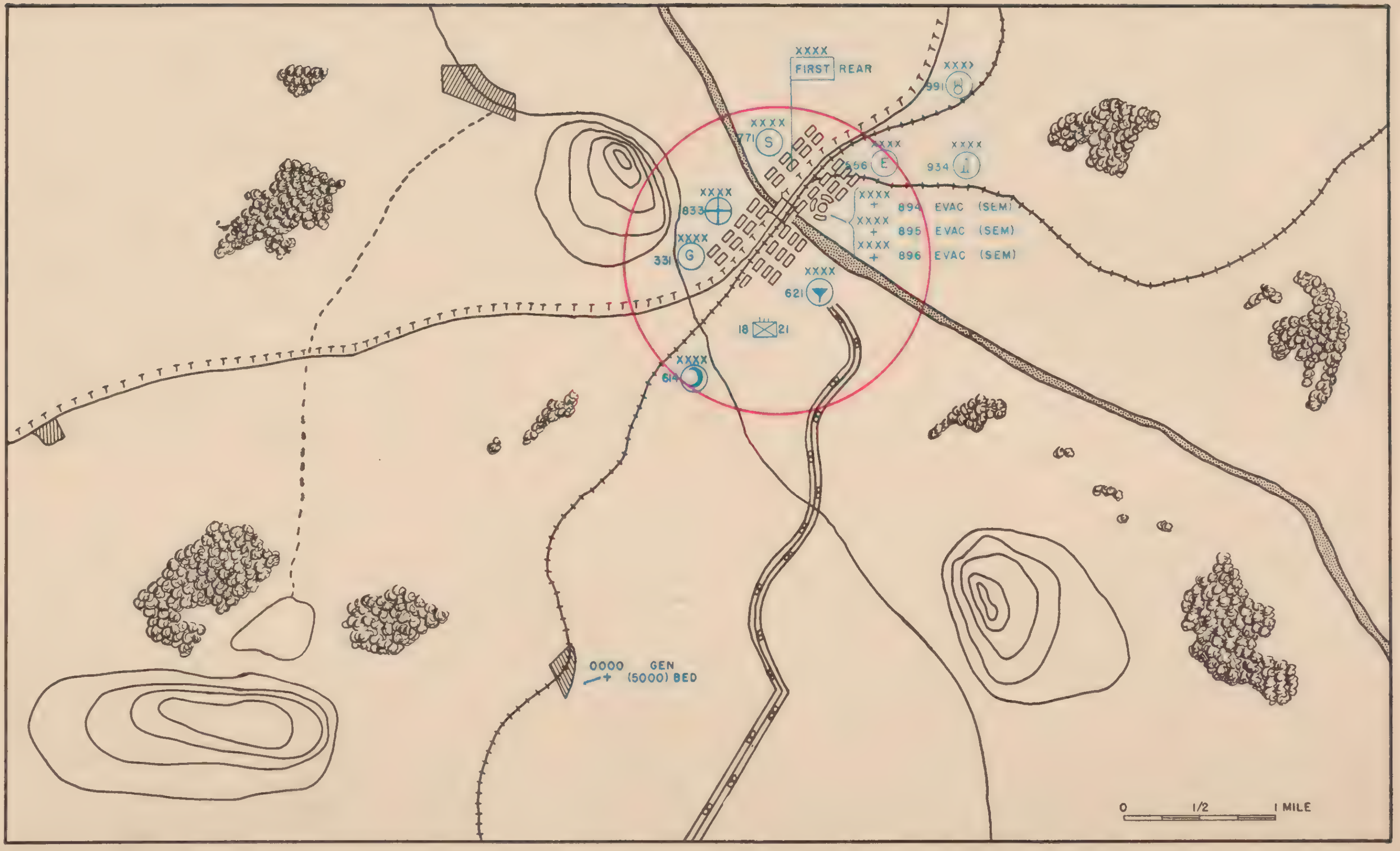


Figure 12.10a. *Map of a typical army rear field installation. The 1 mile-radius circle shown in red indicates the probable extent of severe blast damage to light structures and extensive casualties to exposed personnel, from an air burst of a nominal atomic bomb. Due to insufficient dispersion of the various activities, excessive matériel damage and personnel casualties would be incurred.*

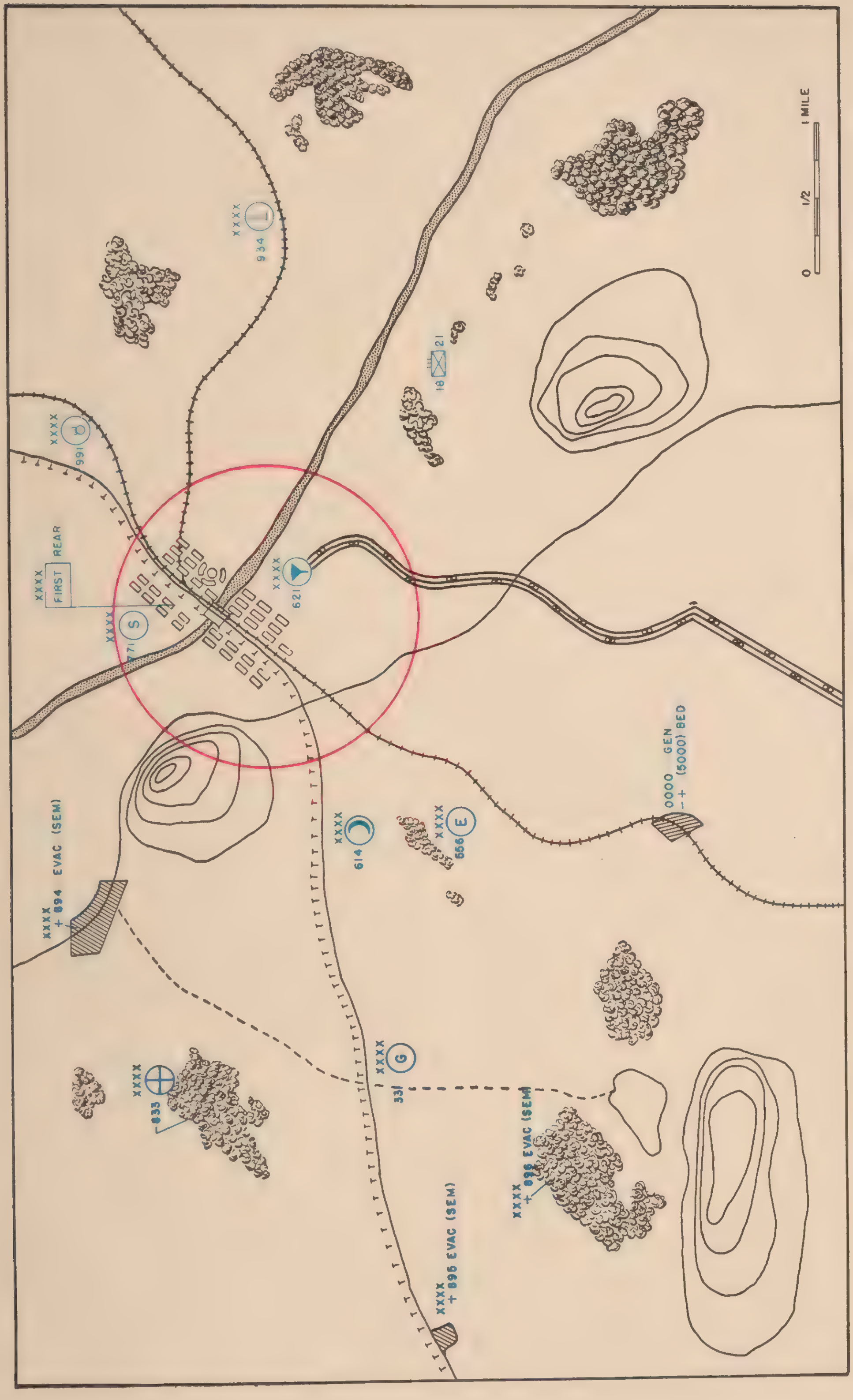


Figure 12.10b. Map of same area as that shown in figure 12.10a, but showing advantages of better dispersion of activities.

EMERGENCY CONTROL ON LAND—ADVANCE PREPARATIONS AT MILITARY INSTALLATIONS

Protection at Existing Installations

12.15. At a military installation on land, it is possible to make certain advance preparations which will minimize the damage and casualties due to an atomic attack. In the construction of new installations, advantage can be taken of the knowledge concerning the effects of atomic bombs to make them much less vulnerable to this weapon. This aspect of advanced preparation however, lies beyond the scope of the present volume. Some consideration will be given, however, to the problem of what can be done at existing installations to minimize the consequences of an atomic attack.

12.16. In the first place an examination should be made of all buildings to insure that vital facilities, at least, are housed in the strongest structures. Command posts, communication centers, hospitals, power plants, water supplies, fire-fighting equipment, and essential stores, for example, should have the maximum protection. Another possibility, if the terrain is suitable, is to construct hillside shelters[1] for the operation of important functions.

12.17. While there are few immediate measures for reducing the damage caused by blast, steps can be taken to reduce the fire hazard. Such steps will minimize the number of fires started and make it less likely that fires will spread, once they have started. An effective fire prevention program requires attention both to individual structures and to the area as a whole.

12.18. Although little can be done to reduce the inflammability of the exteriors of existing structures, it is possible to lessen the danger of fire spread in the interior. Unnecessary inflammable materials should be removed, and those that remain should be kept away from windows and other openings to decrease the danger of fire from heat radiation. The number of secondary fires, caused indirectly by blast (par. 6.21), can be reduced by turning off gas and electricity just before an attack. To simplify this action in permanent installations, the location of utility switches and valves should be marked and should be easily accessible.

[1]The Gasproof Shelter described in chapter 7, section IV, of "Defense Against Chemical Attack," Department of Army Manual, FM 21–40, would be equally suitable for protection against atomic attack.

12.19. The best safeguards against the spread of fires are wide firebreaks and a reliable source of water for fighting fires. Firebreaks, which usually exist in military installations, should be kept free of all combustible materials. Such materials, e.g., wood or cardboard containers, straw, etc., should not be piled, even temporarily, in firebreaks between buildings. Maintenance of the water distribution system is also vital, since water will be required for drinking purposes, for fighting fires, and for decontamination. All shut-off valves should be marked, so that water flowing into broken mains can be quickly cut off.

12.20. Auxiliary sources of water may be necessary to make up for the loss of distribution lines. Consideration should be given to the storage of water in tanks, as was done extensively in Great Britain during World War II, and to the use of wells and reservoirs spaced at intervals throughout the target area. Such sources are, however, to be regarded as a temporary expedient only until the regular system is restored.

12.21. Because the electric supply may be disrupted as a result of an atomic attack, auxiliary power sources should be available for pumping water. Gasoline and Diesel engines can be used for this purpose. In addition, gravity water tanks, if available, would be useful in an emergency.

12.22. A smoke screen will greatly reduce the range of the thermal radiation accompanying an air burst (par. 3.41), and may consequently decrease the probability of fires started by thermal radiation. If proper precautions are taken, the number of such fires will be small in any case, and so the value of a smoke screen is somewhat doubtful. The chief value of a smoke screen would probably be to reduce the incidence of skin burns among unprotected personnel (par. 10.49).

12.23. Contamination of the surfaces of structures and of open spaces cannot be prevented in the case of a subsurface explosion, but the removal of the contamination can be made easier by employing smooth, nonporous surfaces wherever possible. Wood and concrete surfaces can be painted or they may be sprayed with strippable coatings. Painted surfaces can be decontaminated fairly easily (ch. 11) and contamination can be removed by stripping the coating.

12.24. The provision of efficient drainage is another essential step in preparing a military establishment for easy decontamination. As emphasized in chapter 11, before a structure or piece of equipment can be washed down, proper drainage must be available for removal of the waste water. Consequently, another aspect of advance preparation is the proper maintenance of the existing drainage system of buildings and other structures. Where adequate drainage does not exist around buildings, temporary or permanent drainage systems should be installed. Low-lying spots of poor drainage should be located and the situation corrected.

Protection of Personnel at Military Installations

12.25. Consistent with the requirements of the military situation, adequate protection, such as that referred to earlier, should be provided for key personnel. Similar protection for all individuals will, of course, be virtually impossible. Nevertheless, steps can be taken in advance to prepare buried or semi-buried shelters of various types, such as were described in chapter 10. Provided the atomic explosion does not occur close by, fairly deep trenches or other earthworks will offer good protection from all the effects of an airburst.

12.26. The main drawback of simple earth shelters is that they will not keep out radioactive contamination accompanying a subsurface burst or an RW attack. The problem to be solved here is, in some respects, similar to that involved in defense against a gas attack. The ideal solution would be the provision of gasproof shelters,[2] but it may not be practicable to take care of large numbers of individuals in this manner. Gas masks will prevent contaminated particles from being inhaled, but such particles which are deposited on clothing can still be harmful. It may be necessary for personnel to remove their contaminated clothing, and to be decontaminated, as soon as possible.

12.27. In many instances personnel will inevitably be caught in the open when an alert is given or an attack occurs. They should then know what action to take for self-preservation. These actions, described in chapter 10, should be instilled in the minds of all individuals by proper training and indoctrination, so that they become virtually automatic. Training films are a particularly useful aid in this connection.

[2]See Department of the Army Manuals, "Defense Against Chemical Attack," chapter 7, section IV, FM 21–40; "Gas-Proof Shelters," TM 3–350; "Field Fortifications," FM 5–15.

Dispersion of Structures and Personnel

12.28. Dispersion represents a highly effective, if not always practical, procedure for diminishing the effects of an atomic explosion. Such dispersion may be either in space or in time, or both. Dispersion in space, as a means of protection, is well known in military operations, as noted earlier, and the great damage range of the atomic bomb makes it of special value as a defensive measure. In addition to the dispersion of men and equipment, steps can be taken in advance to disperse vital structures and functions.

12.29. The dispersion of structures, as an aspect of advance preparation, is particularly applicable when new military installations are being planned. Buildings should be located as far apart as is consistent with their functions. Advantage can be taken of large terrain features, such as hills and gullies.

12.30. Similar considerations apply to important equipment stored in existing installations. It would be disastrous, for example, if all medical supplies or radiation monitoring equipment were in one building, and this was destroyed. The dispersion of essential matériel and equipment, or the provision of suitable protection, is a matter which must be given thought. In the absence of more elaborate shielding, a considerable degree of protection for valuable supplies might be provided merely by placing them in open excavations of sufficient depth to get them below the level of the surrounding ground.

12.31. Advance plans should be made for the temporary dispersion in space of vital activities. For example, fire fighting and other emergency control units may be moved out of the target area. Commanders should also consider the possibility of temporary dispersion of key personnel when alert of an attack is received, although the necessity for continuing operations might limit the practicability of this type of dispersion. Temporary dispersion can also be applied to ships, both at sea and in port, and to aircraft at an airbase.

12.32. In the case of industrial-type military installations, e.g., shipyards, dispersion in time refers to an operating program which requires personnel to work in three shifts, with individuals of all degrees of importance divided equally among the shifts. Then no matter at what hour the attack comes, only about one-third of the personnel are present. In dispersing personnel by shifts, the main emphasis is on the proper distribution of supervisory and key personnel, so that each shift has all the elements necessary to maintain operations. If one shift is destroyed, the others can train new personnel to fill the gap. During a period of emergency, all essential industrial and military installations would probably operate on a 24-hour basis, and the adoption of the shift system would be automatic.

Decontamination Facilities

12.33. Part of the advance preparations for a contaminating attack is the provision of decontamination facilities for personnel and equipment. Individuals who have become contaminated, as a direct result of the attack, will require decontamination as soon as possible. Others, who have been operating in a contaminated area, e.g., monitors and emergency crews, will require periodic decontamination. Facilities for this purpose may be of an emergency nature, in which the decontamination is performed in the field, or they may be fixed installations. The bathing facilities provided by the Army mobile field unit, or by M3A2, 400-gallon, power-driven, decontaminating apparatus and M1 portable heater, recommended for use against chemical warfare agents, are suitable for field use.[3]

12.34. In many respects removal of radioactive contamination from the body is similar to removal of chemical warfare agents. Precautions must be taken to separate contaminated from uncontaminated sections of the decontamination station. In addition, the problem of drainage of the waste water is of major importance. Careful monitoring, with the appropriate instruments, is required at various stages of the operations and the necessary facilities must be included. The general layout of a personnel decontamination station is described in paragraph 10.71, etc.

[3]See Department of the Army Manuals, "Bath Units, Field, Mobile," TM 10–1696; "Decontaminating Apparatus, Power Driven, M3A2," TM 3–223; "Heater, Water, Portable, M1," TM 3–228.

12.35. Personnel will be monitored before entering a decontamination station, and may have to remove their clothing if badly contaminated. Provision must be made for the proper treatment of such clothing, according to the extent of its contamination. There should be a laundry available to the station for washing contaminated clothing. The mechanical equipment should be so designed that there is a minimum of actual handling of the soiled clothing, and good drainage must be available for the waste water.

12.36. If decontamination of matériel and equipment is to be undertaken at a particular military establishment, then a suitable area will have to be set aside for the purpose. A good supply of water and, if possible, steam and electric power, will be required as part of the facilities. Proper disposal of contaminated waste material to prevent its spread over clean areas is, of course, of vital importance. The size, design, and layout of the decontamination station, including an area for storage of contaminated equipment while awaiting treatment, will depend on the nature of the objects to be treated. The equipment and processes that will be found useful for decontamination purposes are outlined in chapter 11.

Stockpiling of Supplies and Equipment

12.37. Preparation for emergency control operations requires the stockpiling of a variety of supplies and equipment, in unusually large quantities. Much of the equipment required to cope with the effects of an atomic explosion will be the same as for HE, incendiary, and chemical warfare attacks. Firefighting devices, and facilities for rapid repair of power and other utility lines, for example, will be necessary for any emergency, although the quantities needed may be expected to be larger after an atomic explosion. Considerable equipment, ranging from bulldozers to picks and shovels, would probably be required to deal with a large-scale disaster, no matter what its cause. Medical supplies will be needed for the treatment of the injured, but the number of burn injuries is expected to be relatively larger after an atomic attack. In this manual, reference will be made only to such additional supplies and equipment as may be necessary to control the special radiological effects associated with a contaminating atomic burst or an RW attack.

12.38. Monitoring radiac instruments for the detection and measurement of radiation and spare parts for these instruments, should be stockpiled in advance. However, it should be remembered that batteries, for survey instruments, and photographic film, used in some personnel monitoring devices, are liable to deteriorate if stored for a long time. Monitoring teams should also be supplied with portable radios, to enable them to communicate with their control centers, and with means for marking the radiation hazard in different areas. Mobile laboratories will be used, in limited numbers, to make radiological tests which cannot be performed in the field (par. 8.62).

12.39. Various materials, such as soap and brushes for personnel decontamination, and detergents and chemicals will be needed for the decontamination of equipment. It may be mentioned in this connection that the Services are planning to provide a modified, ordinary issue soap, to be in flake or powder as well as bar form, which will contain soap, complexing agent and detergent and thus be of special value for decontamination purposes as well as for ordinary purposes. Special clothing and filter masks will be required for men engaged in decontamination operations (par. 10.66). Similar clothing and masks will also be needed for monitors. Since much of this clothing may be so highly contaminated that it may have to be stored for a time, adequate supplies should be available to allow for this.

EMERGENCY CONTROL ON LAND—BUILT–UP AREAS

Emergency Control Plan

12.40. As stated earlier, military installations, including those located in or near built-up areas, may have to be responsible for, or help with, recovery measures to be taken after an atomic attack. Such a situation might obtain in a communication zone, an advance base, or in the continental United States. An emergency control plan represents an important aspect of advance preparations in this respect. In preparing such a plan, it should be realized that the purpose of emergency control measures is largely to provide help for installations which have been involved in, and whose recovery potentials have been reduced by, the attack. A unit that has suffered in an explosion may be able to do little for itself, and must rely on outside assistance. Therefore, the emergency control plan must make allowance both for self-help and for help to others.

12.41. The actual details of an emergency control plan, or "disaster plan," for any military organization will depend on a variety of circumstances. The main factors to be taken into consideration will be described here; they must be adapted or modified to meet each individual situation. It should be stated at the outset that the matters to be discussed do not include the prediction, detection, and prevention of atomic attacks. The emergency control organization will be essentially of an immediate and local nature. It will be mainly concerned with confining and lessening the effects of an atomic attack in the period immediately after the attack has occurred.

12.42. Since the control measures may have to be undertaken independently, or in cooperation with civil defense authorities, it should be understood that references made below to fire fighters, police, monitors, rescue crews, etc., apply equally to military and civilian components and authorities.

12.43. An emergency control plan must be such that it can be adapted to any kind of burst: either an air burst, in which there will be little or no danger from residual radioactivity, or a subsurface or surface burst, after which radioactive contamination may be serious. In the latter case, and after an RW attack, general and detailed surveys by monitors, in order to mark safe and contaminated areas (ch. 9), will be one of the first requirements. Rescue crews, or their equivalent, will be required, after any type of attack, to assist the injured and to guide them along escape routes to safe areas. In the safe areas, medical units can administer first aid and such other emergency help as may be necessary, and evacuate those who need further treatment to hospitals outside the disaster area. Proper traffic control will be necessary to keep personnel out of danger zones, to avoid congestion, and to prevent the spread of contamination.

12.44. Fire fighting units should set up a defense line on the perimeter of the burning area, choosing positions preferably where they can be supported by other units. It will be the responsibility of emergency repair crews to provide a supply of water for fire fighting and drinking, by repairing broken water

lines and shutting off water to abandoned areas. Finally, if the explosion is one which causes contamination, plans must be made for rough decontamination of certain areas, to permit vital transportation and other operations, and for the decontamination of personnel.

Emergency Control Center

12.45. The units having the various responsibilities referred to above, and which will be considered further in later parts of this chapter, will be directed from the headquarters of the senior command in the area. The command will have the logistic personnel to support the emergency control center which will coordinate and unify the numerous activities for relieving the disaster situation.

12.46. In a built-up area, the emergency control center associated with the senior area commander's headquarters should be housed in an essentially bomb-proof structure, preferably in a location at some distance, 5 miles or so, from the most probable target area. As an added insurance against loss of central control, the agency should split its personnel between two or more stations at widely separated places.

12.47. In case the emergency control center in any particular region is put out of action, the succession of command should be predetermined, particularly in combined operations. The defense organization will then be taken over as quickly as possible by the appropriate alternate command.

12.48. Since mutual support after an atomic attack will be vital, the emergency control center at each installation must have plans for assembling a mobile task force, complete with monitors, fire fighters, police, medical personnel, rescue teams, and repair crews, with their supports, supply, communication, and administrative personnel. The operation of these task forces after an atomic explosion will be described below. In addition to being thoroughly familiar with their own installation, it is important that these mobile support personnel be well informed as to the facilities and capabilities of nearby areas, both military and civilian. This knowledge can only be acquired through effective prior liaison.

RECOVERY MEASURES IN BUILT-UP AREAS

Defense Perimeters in Air Burst

12.49. The measures to be adopted after an atomic attack on a built-up area will be similar in many respects to those which would have to be used after HE and incendiary attacks. However, because of the large-scale destruction resulting from an atomic explosion, the emergency control strategy will have to be somewhat different. In an attack with conventional bombs a number of more or less separate fires will be started in different parts of an area, and the proper defense is to attempt to put out such fires separately, thereby preventing a general conflagration. But after an atomic attack the fires may be so numerous that they will merge rapidly into a general conflagration, and so a different defense technique must be used. For this reason the concept of defense perimeters has been developed.

Fire Perimeter

12.50. The fire following an atomic air burst will resemble a forest fire, in certain respects. It is extremely difficult to extinguish such a fire where it is already established. The best that can be done is to surround the fire and keep it from spreading into lightly damaged zones. To do this a continuous fire perimeter line should be set up at such a distance from ground zero that there is reasonable expectation of containing the fire within the enclosed area. The actual distance will depend on the direction of the wind, the nature of the terrain, and other local circumstances, but it may be about 1 to 2 miles.

12.51. While the fire perimeter should be as close as possible to ground zero, the line should be one which can be held. It should not be so close that fire fighters are forced to retire at certain points, thus destroying the continuity of the perimeter. Consistent with these considerations, it is important that in seeking for a satisfactory position, valuable areas are not abandoned.

12.52. Experience has shown that in fighting extensive fires it is fruitless to attempt to use conventional fire fighting techniques employing cooling methods with water or other means. The only practical procedure is to use fuel removal methods which involve the creation of firebreaks. Such firebreaks should be continuous, if possible, along the fire perimeter.

12.53. Natural firebreaks, such as rivers, lakes, and parks may be utilized, while in built-up areas, wide streets or rows of fire-resistant buildings can act as firebreaks. The minimum width at which a street makes an effective firebreak depends on the height of the buildings. In a city, a 100-foot wide street, if free from debris, would probably be adequate. On the other hand, in a military establishment, where the structures are not so high, a width of 50 feet might be sufficient. A street covered with combustible debris is, of course, worse than useless as a firebreak.

12.54. It may be suggested that while the main fire fighting crews will attend to the major conflagration, the control of the smaller fires outside the fire perimeter can be left to auxiliary fire fighting groups. Such auxiliary groups will probably employ conventional cooling methods, involving the use of water.

Rescue Perimeter

12.55. Beyond the fire perimeter, a second defensive line, called the rescue perimeter, should be established. This will probably be at the rim of the damaged area, perhaps 3 to 5 miles from ground zero. Here, the main defense resources can concentrate so that support can be given to the various task forces, e.g., fire fighters, inside the damaged area. Preliminary medical aid, food, water, and shelter should be made available for survivors evacuated from this area.

12.56. On the rescue perimeter control points will be set up by the emergency control task forces which have come from neighboring areas. These control points, at various intervals, should be subsidiary to, and in continuous contact with, the emergency control center for the disaster area. Task forces will be directed to their respective points in the rescue perimeter by the control center. Their subsequent actions must then be largely on their own initiative, and will be determined by the existing conditions. If for any reason, the control center is not functioning, each task force should be trained to man and operate a control point without specific orders. It is from these control points on the rescue perimeter that fire fighters will move forward, make contact with other fire fighting units, and establish a fire perimeter.

Situation at Military Installations

12.57. If an atomic bomb bursts in or near a military installation, the military will take action for their own protection and, as directed, may also have to furnish assistance to civil defense agencies. The installation may lie wholly within the disaster area, as one extreme possibility, or it may be only slightly damaged, as the other extreme. In the latter case, the installation will lie on the rescue perimeter and will probably form one of the control points. Fire and rescue teams may have to be dispatched into the disaster area, while the base itself is preparing to receive evacuated personnel. If the installation is closer to ground zero, so that it falls in the region of moderate damage, it can perhaps form part of the fire perimeter. The fire fighting units from the base itself will connect with others on both sides. Casualties can then be evacuated to the rescue perimeter, further out from ground zero, where help should be available from emergency control task forces supplied by other agencies.

12.58. Finally, if the explosion has occurred so near to the military installation that it is inside the fire perimeter, heavy damage may have been sustained by both personnel and equipment. It may then be necessary to evacuate the base completely. In this case, survivors should move to the rescue perimeter and either reform their units, or join with other units to aid in damage control. As previously mentioned, this may involve an automatic succession of command to direct operations.

Contaminating Burst

12.59. After a contaminating burst, a military installation outside the target area can send task forces to set up control points on the rescue perimeter, and to carry out radiological surveys. If the installation is situated on the rescue perimeter it could function as a control point, and set up a personnel decontamination station, a hospital or medical aid facility, and a communication center. If close to the fire perimeter, the task forces from the base can control the damage and help to evacuate personnel to the rescue perimeter. Personnel in some other military installation within the fire perimeter may have been trapped in a contaminated area. It may be advisable to have them remain in such shelters as they have available until they receive instructions from the emergency control center.

Defense Perimeters in Subsurface Burst

12.60. The setting up of fire and rescue perimeters after a contaminating attack in a built-up or industrial area will be complicated by the presence of radioactive contamination. In a high air burst, the radiation hazard is all over in a minute or less, and all of the dangers faced by fire fighting and rescue teams in approaching the disaster area will be visible. However, before defense units can enter a contaminated area, they must consider the radiation risk, which can be established only with the aid of suitable instruments as described in chapter 8. Consequently, monitoring becomes an important factor of the emergency control measures.

12.61. Since the radiation intensity will probably be very high within the disaster area immediately after the explosion, it may not be safe for crews to enter the contaminated area for some time. By disregarding the radiation they could perhaps prevent the fires from spreading and evacuate trapped personnel. But afterwards many rescuers, as well as rescued, might suffer from radiation sickness. On the other hand, if the contaminated area were avoided entirely, fires would spread, vital installations might be destroyed, and irrespective of the fire danger, trapped personnel might unnecessarily receive high radiation dosages. The resolution of these conflicting aspects will be a command decision.

12.62. Successful defense involves neither rushing into the contaminated area without consideration of the risk, nor in avoiding it altogether. Consistent with the military urgency, the area should be penetrated carefully, with due regard to the radiation hazard. If conditions permit, entry into a contaminated region should be delayed as long as possible to allow the radioactivity to decay to some extent; thus, between 1 minute and 1 hour after the explosion, the radiation intensity decreases by a factor of over a hundred.

Rescue Perimeter

12.63. Delay in entering the contaminated area does not, however, mean delaying the defense. Systematic control measures can begin immediately. As rapidly as possible after the preliminary radiological survey has been made by aerial and ground monitors (ch. 9), a rescue perimeter, with its control points, can be set up in a safe area. Since the contamination at 1 hour after a subsurface burst will probably not be appreciable at distances greater than 5 miles from ground zero, this will be the approximate radius of the rescue perimeter, just as in the case of an air burst. Consequently, if other information is not available, task forces may choose sites about 5 miles from the estimated point of explosion for the location of their control stations. If possible each location should be checked with an area-survey radiac instrument.

12.64. The basic purpose of the rescue perimeter does not change with the type of burst, and consequently neither do the functions of the control points. However, radioactive contamination makes it more difficult to perform the various functions. Many of the evacuees will be contaminated, and this means that control points will have the added tasks of monitoring, decontaminating, and clothing and sheltering these persons. Spread of contamination to clean areas beyond the rescue perimeter must also be minimized. If the situation permits, all men, vehicles, and materials leaving the disaster area should be monitored.

12.65. In general, the emergency control center will provide control points on the rescue perimeter with an estimate of the degree and extent of contamination, and of the location of the major fires. With this information, a rough indication will be available concerning such matters as the following: the limits of the contaminated area; the regions where the contamination is greatest; the delay necessary for the radiation intensity to fall to an acceptable level; the areas where immediate action is required; and the maximum time workers can spend in such areas. Control points can then send defense units into the disaster area, with the minimum delay compatible with the need for avoiding overexposure to radiation by personnel.

Fire Perimeter

12.66. The establishment of a fire perimeter after a contaminating burst will again present the commander with the necessity for making a choice. If the perimeter is set up close to the badly damaged area, the fire fighters may be operating in a highly contaminated region. On the other hand, if the radius of the fire perimeter is too large, the length of the perimeter will be so great and the concentration

of fire-fighting equipment so small that the efforts of the crews will be virtually ineffective.

12.67. The position of the fire perimeter will generally represent a compromise among the various factors. In most cases this would be determined by taking into consideration the total radiation dosage which personnel would be permitted to accept and the amount of time they would be required to spend in the contaminated area. It would then be possible to set up a line corresponding to a certain radiation intensity which would mark the limit of penetration into the area. This line would serve as the fire perimeter. If a sufficient number of replacements were available, so that each man would be exposed to radiation for a relatively short time, the radiation intensity at the fire perimeter could be higher than if personnel would be expected to remain for a longer time.

12.68. It would appear, as a rough estimate, that the fire perimeter would be set up anywhere from 1 to 2 miles from the center of the explosion depending on the strength of the wind and its direction. A sudden change of wind would, of course, complicate the situation further by requiring a corresponding change in the position of the fire perimeter. The indicated radius might mean the abandonment to fire of many structures which have suffered little blast damage. If this seems inevitable, then there is obviously no point in fire fighters manning the perimeter until the conflagration is approaching it. This may take several hours during which the radiation intensity is falling off appreciably. By delaying entry into the contaminated area for a short time, fire fighting units may accomplish more, at less risk to themselves, than if they rushed in immediately.

12.69. The fire perimeter in a contaminating attack, established as just described, may include installations of vital military importance. Obviously, if these have not been greatly damaged by blast, they must not be abandoned if there is any way in which they can be saved. It may then be necessary, in spite of the added risk, to send special fire fighting missions inside the fire perimeter. However, certain measures can be taken to decrease the hazard to personnel. One possibility is for bulldozers, or other mechanized equipment, to carry out rough decontamination of an area in which fire fighters can operate more safely. Some sort of radiation shielding for crews may be possible and, in any event, there should be frequent rotation of personnel.

12.70. As a precautionary measure, a monitor with a radiac survey meter should accompany fire fighting units, and each crew member should carry a self-reading personnel dosimeter to determine the amount of radiation received. Either the monitor or the control center will estimate the amount of time that can be spent in the particular radiation field. The dosimeters would serve as a check on this estimate. By careful planning, needless exposure to radiation can be avoided.

12.71. Smoke from the fires will represent a radiation hazard to those engaged in fire fighting. As much as half the contamination on a burning piece of material may come off with the smoke and gases. To protect themselves, fire crews should avoid smoke wherever possible. They should wear dust respirators and masks to prevent inhalation of the contaminated smoke and dust.

Survey and Marking of Radiation Hazard

12.72. After a high air burst, the radiation hazard on the ground will be negligible, and although some monitoring may be desirable, for psychological reasons, as well as to determine the inhalation and ingestion hazard, the defense perimeters can be set up without delay. Following a contaminating attack, however, monitoring becomes an urgent responsibility of the defense organization. Without this it is impossible to establish fire and rescue perimeters which can be held. The various types of survey described in chapter 9 will consequently be carried out, and the data transmitted to the control center for entry on the dose-rate map (fig. 9.30b).

12.73. Much of the information from the radiological survey will be required for future planning, but immediate steps must be taken to mark contaminated areas and equipment. This work will probably be performed by area-survey monitoring crews who will carry with them suitable markers. The standard triangular markers (fig. 9.36) may be supplemented by others, such as red and yellow colored signs, or by means of colored paints.

12.74. Since personnel approaching an area might not know whether it has been monitored or not, it would seem advisable to consider the use of a system

of marking areas and objects which have been monitored and found safe. Access routes and roads which are either uncontaminated or which have been decontaminated should be marked in any case. This will prevent them from being used by contaminated vehicles and equipment.

12.75. Because of the decay of radioactivity with time, the position or color of the markers would have to be changed from time to time. An area or piece of equipment, which cannot be approached one day, may possibly be used for a short time on the following day.

Rescue Operations on Land

Rescue Teams

12.76. As soon as possible after an atomic attack, rescue teams should enter the disaster area to free persons trapped under debris, to administer or advise on first aid, and to help the injured out of the area. Their equipment should include portable radios, for communicating with other teams and with the emergency control center, and maps of the area, for locating access and escape routes, shelters, etc. They should carry road markers for indicating clear routes and first aid packets for distribution to the injured. In addition, personnel dosimeters and radiation survey meters will be required, particularly after a contaminating burst. A bulldozer, if available, might be of great help in clearing routes for access of fire fighting and rescue teams.

12.77. The work of rescue crews after a contaminating burst will be extremely difficult, for they will be greatly hampered by the radioactive contamination. While rescue workers will do all they can to save trapped persons, they should also endeavor to protect themselves. However, rescue teams need not wait for the results of the preliminary radiation survey before entering the disaster area since they are equipped with their own radiac instruments. Inasmuch as every minute spent in the contaminated region is important, rescuers should not travel on foot, and every effort must be such that it will give results quickly. Trucks or tractors or, better, tanks or armored cars, can be used for transportation. The latter, in particular, will provide some shielding from gamma radiation. Fast vehicles should, if possible, also be used for evacuating persons from a contaminated area.

12.78. Rescue of persons trapped in collapsed buildings or buried shelters requires experienced workers with various engineering skills, to constitute rescue teams. In the Army, an Engineer squad, with its regular equipment, supplemented by radiac instruments, would represent a good example of such a team. The principal additional items of equipment which would be desirable are an air compressor and bulldozer. If these are unavailable then work would have to be done with hand tools and rigging equipment. In the Navy, a group of Seabees would constitute an effective engineering rescue team.

12.79. Engineering rescue crews will normally work only between the fire and rescue perimeters, starting just beyond the fire perimeter and moving outward. There are two reasons for this. First, the rapid approach of the fire will mean that there is insufficient time for engineering rescue within the fire perimeter and, second, many more people will still be alive, and require rescuing, in the zone between the two perimeters than within the fire perimeter.

12.80. So that no move should be wasted, engineering rescue must be carried out systematically. The first step is a rapid preliminary survey of a fairly large area to determine the nature of the tasks ahead and to make a working estimate of the time required for each. This survey will permit the team to concentrate on the most urgent tasks, and especially those which can be completed in a short time. Lightly damaged structures should be left to the attention of auxiliary or volunteer workers with less experience.

12.81. Engineering rescue work in a contaminated area will be almost impossible, at least for the first day. By the very nature of the operations, crews must spend a considerable time at the rescue site. Unfortunately, the areas in which engineering rescue is needed probably will be highly contaminated. This means that very little engineering rescue can be carried out in the first 24 hours after a contaminating burst. However, some special missions may be attempted during the period by rotating personnel engaged in the rescue work.

Medical Aid

12.82. The techniques of treating the injured after an air burst will be the same as after any other

disaster, and the established procedures will be used. The main difference will lie in the very large numbers of persons who will require attention after an atomic attack. Consequently, every medical facility and organization in the range of the disaster area must be mobilized. Because of their mobility and applicability to the situation in either the communication zone or in the zone of interior, Mobile Surgical Units and, to some extent, Field Hospitals and Evacuation Hospitals, will be especially useful.

12.83. Medical aid stations of military units and their stocks of supplies will form an important part of the control points on the rescue perimeter. Here such treatment as is possible in a short time will be given, and persons requiring further attention will be evacuated to hospitals outside the perimeter.

12.84. The treatment of injured persons who are contaminated will not be simple. They must be monitored quickly and those carrying dangerous amounts of radiation should be decontaminated. Medical aid units should give special care to contaminated wounds. However, as already stated, there is little or nothing that need be done in the emergency control stage to help those who have received appreciable doses of radiation except for treatment of other injuries.

Emergency Repairs

12.85. Repair and restoration of essential utilities is the only type of repair that can be undertaken as part of the emergency control operation. The responsibility for such repairs is already well established within the military service and the work should, if the situation demands, be done in cooperation with the regular civilian agencies. Skilled and experienced workers, with adequate equipment and spare parts, will be required to repair electrical and water systems as rapidly as possible. While broken fuel lines need not be restored immediately, the fuel must be stopped from leaking out and creating an added fire hazard.

12.86. When repairing power lines in a contaminated area, it would be preferable to work from regions of low intensity to those of higher intensity. In this way the more highly contaminated areas will have additional time to decay before it becomes necessary to work in them.

Police and Traffic Control

12.87. After an atomic explosion, there will be an immediate need for traffic control and the maintenance of order, particularly in a built-up area. Evacuees will stream out of the damaged zone, blocking all roads not already cut off by fire and debris. At the same time, access routes must be kept open for defense teams to enter the disaster area. Large numbers of persons will collect in the safe areas at the rescue perimeter. A considerable force of police, both military and civilian, will be required to prevent the situation from getting out of hand.

EMERGENCY CONTROL MEASURES AT SEA—ADVANCE PREPARATION

Damage Control Plan

12.88. The existing ship damage control organization, which vessels already have, to deal with the effects of conventional weapons, such as HE bombs, shells, mines, torpedoes, and depth charges, will go a long way toward controlling the damage resulting from an atomic attack. There are, however, two additional factors in the latter case which must be taken into consideration. First, the effects of an atomic explosion will usually be over the whole vessel, and are not localized as is generally the case with conventional weapons. Second, if the atomic bomb explodes under the surface of the water, radioactive contamination may interfere with normal emergency operations.

12.89. After an air burst, there will be little or no residual radiation hazard, and the damage control organization can function in the same way as after an attack with ordinary bombs, shells, etc. But since a ship may be exposed to atomic explosions either in the air or beneath the surface, or both, adequate preparations must be made in advance to deal with radioactive contamination. For this reason every ship must set up a radiological defense bill which should be a part of the existing damage control bill.

12.90. In order to prepare for the possibility of widespread damage throughout the ship, commanding officers must evaluate their present shipboard equipment to see whether it is adequate for control of damage on a large scale. Tools, shoring materials, pumping facilities, etc., should be sufficient to deal

with the flooding of several compartments at the same time, instead of one or two. The same considerations would apply in connection with the equipment and materials required for the control of all other forms of damage.

12.91. Because an atomic attack may result in casualties from one end of a ship to the other, the dispersal of personnel topside, i.e., horizontally, may not be effective. If the commanding officer and the executive officer are located on the same, or nearly the same, deck level, they may both be incapacitated, even if one is stationed forward and the other aft. It might consequently be preferable to divide key personnel between duplicate fire control, secondary control, damage control, and other stations set up at widely spaced levels on the ship. In other words, the dispersion should be vertical rather than horizontal. Consideration should be given to the added protection afforded by spaces in the center of the ship below the water line or by strongly armored areas, with due regard for the calculated risk.

12.92. The suggestions concerning the location of key officers applies in a general way to all other members of the crew. Casualties can be kept to a minimum by utilizing existing shelter to its fullest extent. Such action could very greatly reduce the casualties from nuclear and thermal radiation, in the event of an air burst, or from the base surge, following an underwater burst.

12.93. In order to meet the problems introduced by radioactive contamination, the ship's organization must include arrangements for monitoring and decontamination. At least one member of each damage control party should be able to use radiac instruments, and electronic personnel should be trained in the maintenance and repair of these instruments. Personnel decontamination stations should be prepared and men allocated for the necessary operations. Others should be responsible for the rough decontamination of areas and equipment. In addition, all members of the crew should receive proper indoctrination and training in radiological matters, including methods of self-protection (ch. 10).

12.94. After a contaminating attack monitoring functions must be performed as rapidly as possible. Consequently, it is desirable to prepare a monitoring plan in advance. The actual plan adopted will depend on the size and nature of the ship.[4] Equipment and stations vital to the safety and operability of the vessel should, of course, be given priority. The results of the monitoring survey should be communicated immediately to the central control station, from which instructions for repair and rescue operations will be given.

Mutual Aid

12.95. In preparing for atomic attack, the principle of mutual aid is of the greatest importance A vessel may become so badly damaged or contaminated by the base surge and fall-out that it needs assistance. Consequently, preparations must be made on each ship so that no time will be lost in helping a stricken vessel with fire fighting, decontamination, and, if necessary, removal and decontamination of personnel. Naval vessels have long had organized "fire and rescue" parties whose basic training and equipment, supplemented by radiac, is well suited to this purpose.

12.96. A somewhat unlikely, but not impossible, condition is that in which a ship is so badly contaminated topside that members of the crew, who are safe in the interior, cannot get out to perform even rough decontamination. In a case of this kind, another vessel could come to the rescue by hosing down the contaminated ship from a distance. The same procedure would be useful in decontaminating a vessel which has had to be abandoned by its own personnel (fig. 12.96).

Protective Measures

12.97. While it is possible to incorporate into new ship construction certain design features that will minimize the damage caused by an atomic explosion, this is a long-range problem which will not be considered in this manual. There are, however, many protective measures that can be adopted in existing vessels that will make them less vulnerable. Some of these will be indicated briefly; they should suggest other steps of a similar nature that could be taken, according to the character of the ship.

12.98. Naval regulations require periodic inspection of materials and structures to determine corro-

[4]See "Radiological Safety Manual," Chief of Naval Operations, Navy Department, USF85.

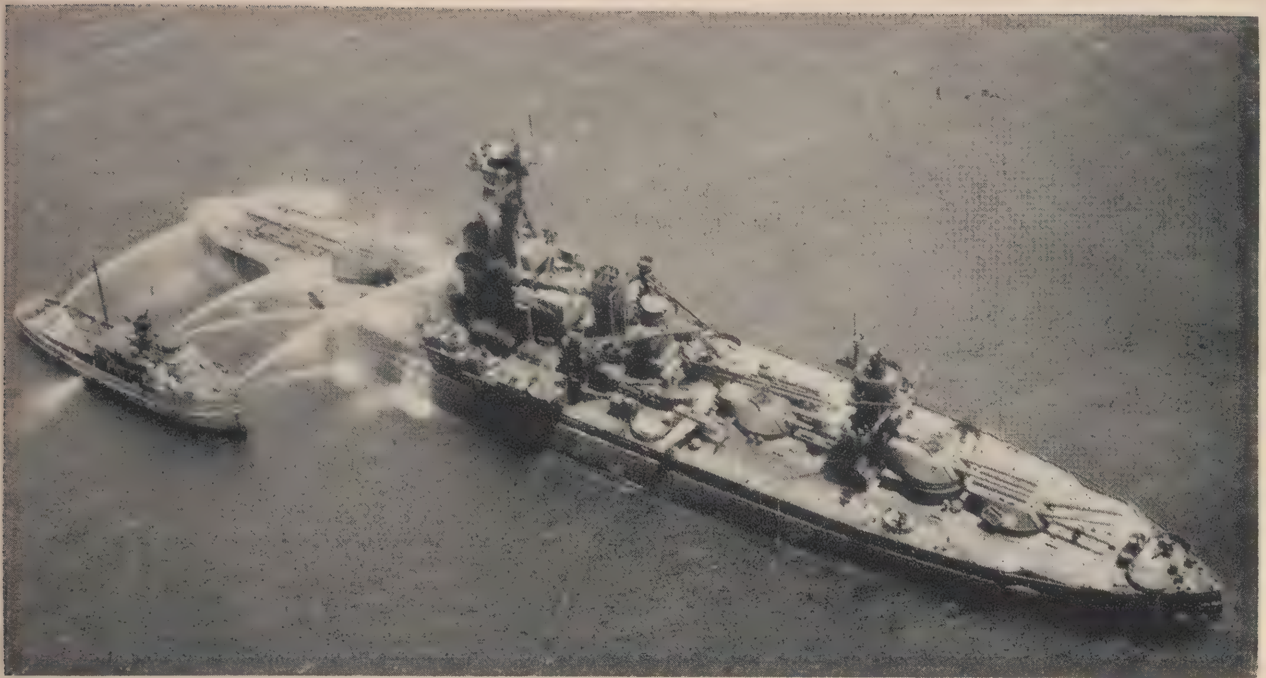


Figure 12.96. Rough decontamination of the NEW YORK, after Test Baker at Bikini, by hosing down with sea water from a Navy rescue tug.

sion, especially in places where deterioration is likely to exist unobserved. Such places are boiler seatings, stack breachings, sea chests, hull fittings, and bulkheads and frames in tank spaces, etc. These inspections assume added importance in view of the possibility of atomic attack. Corroded surfaces are particularly susceptible to contamination, and deteriorated places are, of course, those which are likely to give way under the influence of blast and shock.

12.99. Following an underwater burst the base surge will constitute a possible hazard. However, if the interior of the ship is water-tight and the ventilation system is shut down completely, the entry of the base surge can be prevented. Since about a minute will elapse before the base surge overtakes a moderately undamaged ship, there should be time for personnel to take appropriate cover and for the ship to be secured by closing all ventilation intakes, doors, and hatches. This is an operation which can be planned and practiced in advance, so that it can be performed as quickly as possible. Within 5 minutes the base surge probably will have dissipated, and emergency control operation can be started.

12.100. It was stated in paragraph 11.38 that if topside structures are wetted with sea water before an atomic attack, contaminated particles can subsequently be removed much more readily. It is expected that, where practicable, future ship design will make provision for a "water curtain" for flushing weather surfaces prior to an attack, and for subsequent possible decontamination. Generally, however, the ship's fire hoses may be used to drench all exposed topside surfaces. Trial experiments will indicate how quickly the wetting-down operation can be performed. In the event of an alert, the commanding officer will then have some idea of whether members of the crew have time to spray important exposed areas.

12.101. Since porous materials cannot be decontaminated once they have soaked up radioactive material, manila and canvas should be stowed, if possible, where they cannot be wetted by rain or spray.

12.102. After an air burst there will be no base surge, but the nuclear radiation emitted at the time of explosion is just as lethal. Since 50 percent of this radiation is given off within a second of the explosion, there will only be time, at best, for an individual in the open to drop to the deck after seeing the flash of the explosion.

12.103. As a help in determining suitable locations, or improving the shielding of existing ones, a comparison of the shielding values of four important materials, commonly found on ships, is given in table 12.103. The figures in the second column are the thicknesses in inches which are equivalent to 1 inch of steel in attenuating the nuclear (gamma) radiation. Although the shielding value of some materials is quite small, *any shielding is better than none.* Effective protection of even part of the body would help to minimize radiation casualties.

Table 12.103. Comparison of Shielding of Materials with that of Steel

Material	Inches equivalent to 1 inch steel	Location
Fresh water	8	Tanks
Salt water	8	Tanks
Oil	9	Tanks
Aluminum	4	Deckhouses

12.104. In order to prevent possible contamination of the potable water supply, preparations should be made for securing evaporators prior to an attack. If the supply of boiler feed water is critically low, it might be necessary to continue to run the evaporators to provide water for boilers. In this event, the water must not be diverted to potable water tanks unless it has been established that there is no danger of contamination.

Dispersion and Evasive Action

12.105. Dispersion as a protective measure was abandoned by the Navy in World War II as being less desirable than concentration of fire power. However, the advent of the atomic bomb, with its great damage range, has again made dispersion desirable in certain circumstances. The advantages of dispersion must be carefully weighed against the desirability of concentrated antiaircraft fire power and antisubmarine protection.

12.106. An important aspect of dispersion is the evasive action that could be taken by a ship to avoid entirely or to delay the time of entering the contaminated base surge fog. As seen in chapter 4, the base surge does not commence to form until 10 seconds or more after the underwater explosion. Its outer front is then about 400 yards from surface zero and it moves forward, first rapidly and then more slowly, until it attains a radius of about 2 miles at the end of 4 minutes. Subsequently, the base surge dissipates, and it ceases to be an immediate hazard. If the base surge can be avoided in its earliest stages, when the radiation intensity is highest, its harmful effects will be greatly reduced.

12.107. When envelopment by the base surge is inevitable, the proper maneuver is that which will delay contact for the longest possible time. In all cases this will be a turn to put the point of the underwater explosion astern, without regard to the direction of the wind. The time of entry into the base surge is vastly more important than the total time spent in it. The reason for this is that the level of activity is decreasing at an extremely high rate. An additional consideration is that the outer fringes of the base surge are much less radioactive than the interior. Therefore, an effort should be made to avoid deep penetration of the base surge by the ship. Once the ship is within the base surge, the maneuver should be one which will favor the earliest possible exit.

12.108. Within the bounds of a single ship, dispersion in time, such as is suggested for operations on shore (par. 12.32), is not feasible. There should, however, be dispersion of personnel, especially key officers, as indicated above. Ways and means should be planned for relocating personnel and functions aboard ship so that no vital post will be immobilized or left vacant by damage or casualties.

Decontamination Stations

12.109. After a contaminating attack a large number of a ship's personnel may require decontamination. It is necessary therefore that appropriate changing and bathing facilities, as described in chapter 10, with properly marked access routes, should be set up in advance in shower rooms or other compartments where there is a supply of water for washing. For large ships a minimum of three decontamination stations would appear to be desirable—one forward, a second amidships, and a third aft. The medical aid unit should be close by, so that special decontamination of wounded personnel may be performed.

12.110. For the change rooms to be effective, supplies of clean clothing must be provided as well as

proper receptacles for discarded contaminated clothing. Provision must be made for the laundering, storage, or disposal of the clothing according to its degree of contamination.

Stockpiling

12.111. As stated earlier, the fact that an atomic explosion may cause damage simultaneously over a large part of a ship means that more damage control, and similar, equipment and spare parts will be necessary than has hitherto been adequate. This fact must be borne in mind in stockpiling materials in preparation for an atomic attack. Such materials are, however, no different in character from those with which damage control organizations are already familiar.

12.112. In addition, a number of items for dealing with the radiological effects of atomic weapons will be required. Chief among these will, of course, be radiac survey instruments and personnel dosimeters. Changes of clothing will be needed for persons who have become contaminated, and special waterproof clothing, gloves, etc., will be required for members of the crews assigned to decontamination work (par. 10.66). Existing equipment on ships, such as respirators and hose masks, will be used where necessary.

RECOVERY MEASURES AT SEA

Damage Control After an Air Burst

12.113. Damage control at sea, following an atomic air burst, presents essentially no new problems. Damage will be greatest throughout the superstructure (ch. 6). There will be no significant residual radioactivity (par. 3.60). If the ship has been properly prepared before the attack there will be few, if any, fires originating from the thermal radiation.

12.114. Reflected blast may cause some damage to boilers and boiler casings, and these should be examined. The ventilation system is especially vulnerable to blast, and it should be checked before being started up again. Although the hull will probably not be damaged if the ship is more than 800 yards from surface zero, the portion of the hull above the water line should be inspected.

Damage Control After an Underwater Burst

12.115. Damage control after an underwater burst may be complicated by the presence of contamination. If good closure was effected prior to the attack and if the weather envelope of the ship has not been breached, contamination will be confined largely to topside. In this event, recovery will not be too difficult, provided due care is taken.

12.116. One or more members of each repair party must be trained in survey monitoring, and all personnel should, of course, wear dosimeters. The radiation intensity in the area where the repair is required will then determine the subsequent procedure. If the repair is essential, and the contamination is high, it may be necessary to proceed without delay and replace personnel at short intervals. In this case, the repair party may require additional help.

12.117. If the damaged and contaminated equipment is not required immediately, it can be left for the activity to decay. In order to make sure that it is not touched or approached, monitors should mark it in some agreed manner. Similarly, contaminated areas should be designated by means of markers or by colored chalk or paint. In some areas it may be desirable to indicate equipment which has been monitored and found to be free from contamination.

12.118. Because of the pressure on the damage control organization after an atomic explosion, repair parties should be encouraged to act on their own initiative and make their own decisions whenever possible. Fortunately, existing damage control regulations provide for a great deal of authority to be vested in the repair party chief. After consulting with his monitors, he can decide what action to take. In some cases, it may be necessary to perform rapid, rough decontamination of areas or equipment by hosing with water before repair work can be started (par. 11.37, fig. 12.118).

12.119. Portions of the ship below decks may become contaminated due to entry of the base surge or as a result of flooding by contaminated water. Both cases will present serious problems because they may render the ship uninhabitable. A very thorough monitoring, especially of galleys, messing compartments, living quarters, and important stations will be necessary (par. 9.49).

Figure 12.118. Damage control crew hosing down topside of the SALT LAKE CITY after Baker Test.

Medical Aid

12.120. A significant aspect of the treatment of the injured is first aid (par. 7.70). This is already emphasized as part of normal practice; men are instructed to administer first aid to wounded shipmates, attention at battle dressing stations being given later if required. Since the number of casualties may be large after an atomic explosion, first aid will be especially important. In indoctrinating personnel about atomic effects, radiation casualties should not be stressed, although it should be emphasized that there is no danger involved in touching persons who have been exposed to nuclear radiation. The effects of an overdose of radiation are not felt immediately, and so first aid treatment should follow conventional techniques and methods for the treatment of mechanical injuries and burns.

12.121. The medical officer should keep track of the radiation exposures, as indicated by individual personnel dosimeters, or by instruments placed in

advance at selected positions on the ship. In this way, it may be possible to avoid further exposure of men who have already received the maximum radiation dosage permitted in the circumstances. In addition, the commanding officer then will know how many members of the crew are likely to become radiation casualties (par. 7.40) and can plan his future actions accordingly.

Decontamination

12.122. In addition to decontamination of personnel, mentioned above, a certain amount of rough decontamination of the ship and its equipment may have to be undertaken. After a contaminating attack the superstructure should be hosed down with sea water, as soon as possible. This washing will remove a large proportion of the contamination, especially if the wetting-down operation has been carried out prior to the attack.

12.123. The main purpose of this rough decontamination is to reduce the radiation hazard sufficiently to allow personnel to work for short periods, at least, and in a manner that will not seriously affect efficiency. More thorough decontamination, which will be undertaken later, can best be effected by salvage vessels or at a repair base (ch. 11).

12.124. As in all emergency control operations, priority in the rough decontamination immediately after an attack should be given to the vital ship and fire control stations. Where it is possible, within the limits set by this essential requirement, decontamination should be carried out in such a way that surfaces which have been decontaminated will not later be contaminated again by material removed from other surfaces. In general, this means working from higher to lower levels, and from bow to stern (par. 11.37).

12.125. If below deck spaces require emergency decontamination, due regard must be paid to the possible flooding resulting from the use of large quantities of water. In such cases, steam from existing lines, in conjunction with detergents, can be employed with advantage. Because of the difficulties involved, decontamination of electrical equipment should not be attempted unless it is absolutely essential. Isolation is a better expedient, provided the equipment is operable or replacements are available.

EMERGENCY CONTROL MEASURES IN THE AIR

Avoidance of Atomic Cloud

12.126. Although the explosion of an atomic bomb can cause both blast and heat damage to an aircraft in flight, these effects are not considered important from the standpoint of emergency control. There is little that aircraft within blast and thermal range can do to protect themselves. The principal hazard of an atomic bomb detonation to aircraft in flight, against which protective measures are possible, will be due to radioactive contamination.

12.127. Flying through the atomic cloud, within an hour or two of the detonation of the atomic bomb, will result in the deposition of a considerable amount of contamination on the exterior of the aircraft. The gamma radiation coming from this contamination, as well as that from the main body of the cloud, will represent a serious hazard to members of the crew. The only way in which this particular danger can be eliminated is for aircraft not to fly through the cloud soon after its formation. It is contemplated that some aircraft will have instruments which will help them avoid an atomic cloud, or directions can be supplied by a control center responsible for the collection of radiological data.

12.128. There are at present in existence, for normal operations, several major aircraft control systems. These organizations, with their individual communication networks, are capable of receiving radiological information, studying the problems arising from such information and transmitting the operational decisions directly to the pilots and crews concerned. With very few exceptions, all flights are in constant communication with one or other of the control services.

Protection Against Internal Hazard

12.129. There will be very little internal hazard in a plane flying through an atomic cloud provided proper use is made of available facilities. Protection to air crews and passengers can be obtained by wearing oxygen, filter, or service gas masks during the period in which there is a possibility of material entering the aircraft's ventilation system.

Protection of Maintenance Crews

12.130. In flight, large volumes of air pass into an engine, especially a jet engine. In the course of a

protracted flight, through a dispersed atomic cloud, a considerable quantity of contaminated particles might consequently collect in the engine of an aircraft. While this will probably not represent an appreciable hazard to the members of the flying crew, it might be a hazard to maintenance crews.

12.131. Reduction of the radiological hazard can be provided by the use of dust filters on the intake systems and carburetors. These filters might become badly contaminated, so that they should be approached with care. However, it is easier to remove them than it would be to decontaminate the interior of the engine.

12.132. The usual aerodynamic benefits from keeping aircraft clean will be enhanced by the resulting reduction of contamination hazards. Radioactive particles tend to adhere to oily surfaces (par. 6.131). Consequently, any steps taken by ground crews to reduce oily areas on fuselages or within nacelles will pay off in reduced work load and diminished hazard should decontamination be required later.

Control Measures After an Atomic Explosion

12.133. Immediately after an atomic explosion, reports will be received at the appropriate control center from aircraft spotters, intelligence, mission strike reports, or other sources, on the general air communications network. These may be supplemented, if considered necessary by the command, by information concerning the atomic cloud obtained from special survey aircraft. The assigned personnel at the control center will then plot the "air radex," that is, a contour type representation of the contamination pattern of the atomic cloud and its predicted travel. This radiation pattern is plotted on the map of the area over which the center has control.

12.134. The operations officer will thus have a picture of the cloud, its probable speed, and the location of aircraft within his control sector. By means of radio, he may suggest course changes directly to pilots, or he may communicate with them through the flight clearance section at a nearby airbase. In making such suggestions, account must be taken of such factors as priority of the mission, meteorological conditions, protective devices installed in aircraft, etc.

12.135. Vectoring aircraft to avoid the atomic cloud is only one function of the control center. Another important service will be to furnish technical assistance to crews of contaminated aircraft. For example, if an aircraft has flown through the atomic cloud, the control center would be able to calculate the total dose which would be received during the mission and advise the plane commander accordingly.

12.136. A potential hazard, affecting aircraft in flight in an indirect manner, would be the contamination of an airfield after a subsurface burst. The aircraft would then be diverted to an alternate base. In general, the combination of radiological and operational information available at the control center would be of considerable benefit to pilots.

12.137. The planning of air missions after an atomic explosion must take into consideration the possible radiological hazard. In addition, photographic reconnaissance sorties over the target area must be planned in such a way as to minimize contact with the cloud, since gamma radiation will fog film in a manner similar to that which produces a film badge record (par. 8.44). Transport aircraft may be required to evacuate or supply a contaminated area, while other aircraft will undertake monitoring from the air (par. 9.08). In all cases, operations staffs, familiar with radiological problems, must recognize both the radiation exposure of the air crews and the possible contamination of the aircraft. With proper training, sound planning, and good organization, radiological hazards can be reduced to the point where they are not a serious operational problem.

SUMMARY

Proper planning is required to minimize damage from an atomic attack, and to speed recovery. In the field, normal procedures, such as dispersion and shelter in foxholes, etc., will provide valuable protection. After a surface or subsurface burst, contaminated equipment, if urgently needed, can be roughly decontaminated. Command and logistical activities, and transportation can be made less remunerative targets.

Measures can be taken to make existing military installations less vulnerable. Shelter can be provided for personnel. Important functions, equipment and supplies should be dispersed, as far as possible. Decontamination facilities should be provided.

Military installations near cities may be called upon to assist with, or to take charge of, recovery measures in built-up areas. An emergency control plan should be prepared, suited to the existing circumstances.

Recovery measures in a built-up area require the establishment of fire and rescue perimeters immediately after an attack. Fire-fighting, rescue, monitoring, emergency repairs, medical aid, and police control operations will be necessary.

On a ship there should be a radiological defense bill as part of the existing damage control bill. Essential functions should be dispersed vertically and duplicated, if necessary. Steps can be taken to make the vessel less vulnerable and to protect personnel in an atomic attack. Damage control at sea presents essentially no new problems except that of possible contamination. Rough decontamination will reduce the hazard to personnel and thus aid in preserving the military efficiency of the vessel.

In the air, the principal hazard against which protective measures are possible is that due to radioactive contamination. Advance action can be taken which will reduce the hazard to flight crews and maintenance crews. After an atomic attack, a control center should direct aircraft so as to minimize exposure to nuclear radiations.

CHAPTER 13

MILITARY ORGANIZATION AND TRAINING FOR ATOMIC DEFENSE

GENERAL FUNCTIONS

Introduction

13.01. In general terms, every special defense organization within the military structure, whether it be for defense against chemical attack, incendiaries, or HE bombs, has the same objectives. These objectives apply equally to the organization for atomic defense, and may be summarized as follows:

(1) To enable the unit to carry out its mission with a minimum of interference under attack.
(2) To prepare the unit concerned to meet attack.
(3) To minimize losses in personnel, equipment, and facilities.
(4) To render such emergency assistance as may be possible to neighboring units and, when directed, to civilian installations.

13.02. As has been stated previously in this volume, the problems presented by an atomic attack differ principally in magnitude from those already well known since the introduction of saturation bombing. This is particularly true for an atomic attack in the form of an air burst. The one new problem introduced is that of the radiation hazard, which may arise from the immediate nuclear radiation of an air burst, from the transit dose of a base surge, or from the residual contamination remaining after an atomic explosion or RW attack.

13.03. Although radioactive contamination, due to a subsurface or surface atomic burst, is a novel feature of warfare, the methods of dealing with it are essentially those which would be employed to cope with chemical (and biological) contamination. Thus, a commander in the field, faced with the problem of a radioactively contaminated area, would either—(*a*) go around the area, (*b*) decontaminate the area or a path through it, together with matériel within it, or (*c*) if time allows, ban all but necessary access to the area until the hazard has decreased, by natural decay, to an acceptable level. These alternative procedures would apply equally to an area contaminated with chemical agents, except that, in this case, the hazard would be decreased by the action of wind and weather, rather than by natural decay.

13.04. The techniques of decontaminating a radioactively contaminated area will be, to a certain extent, different from those used to remove chemical contamination, but many of the same personnel, wearing similar special clothing, directed by the same officers and noncommissioned officers, will perform the work. In many cases, too, they will use the same equipment.

13.05. The conduct of atomic defense thus requires no important change in the present military structure, although it does require additional training for existing specialists and, in some cases, the complete retraining of individuals selected for special functions. In addition, atomic defense requires service-wide indoctrination and training for all personnel. However, no reorganization is required, and no new defense organization need be superimposed on the existing one.

13.06. Some of the technical knowledge required by a commander for properly conducting atomic defense is specialized. But, as with other functions, such as communications, logistics, intelligence, etc., commanders will have staff advisers in atomic defense. The duties of these staff advisers are described later in this chapter.

Planning for Atomic Defense

13.07. Before discussing the current organization of the Armed Forces for atomic defense, certain general principles may be examined. These principles are basic, and are common to all three Services; they should be borne in mind in the planning and implementation of atomic defense organization and procedure.

13.08. A unit or installation commander, whether in the field, afloat, or in a rear area, should realize that an atomic attack on his unit or in his vicinity would probably effectively saturate his defensive capabilities. In such circumstances, his recovery would be largely dependent on assistance provided by neighboring units. Therefore, each commander's defense plan should provide for *mutual aid* to military units and installations in his area, and also, as applicable, to neighboring civilian communities (ch. 12).

13.09. In order to achieve the maximum effectiveness in this connection, there are two essential requirements—

(1) Defense planning should be coordinated through progressively higher headquarters, for maximum mutual support preparations.

(2) Provision should be made at the appropriate command level for mutual aid between neighboring military units or establishments, even though these may be of different Services, and with widely differing functions. In practice, this should be arranged through close liaison between the defense organization of the two installations, and integration of their defense plans, with necessary approval of the higher headquarters of each.

13.10. Defense planning should be as specific as possible under the existing conditions. In the relatively static conditions of an advance base or communication zone, or in the continental United States, in particular, planning should be specific and detailed with respect to responsibilities and procedures. Each individual must be able to evaluate properly the effects of an atomic attack, to understand his responsibilities, and to perform his duties efficiently to minimize these effects.

13.11. As stated previously, the problems of atomic defense require no fundamental change in existing organizational structure. The well-defined functions and responsibilities of the principal components of military organizations need not be changed, but *their capabilities must be enlarged* to permit them to recover from the massive impact of an atomic attack. For example, medical evacuation and hospitalization capabilities will be strained to the utmost. So also, in a field situation, will be the ability of the Signal Corps to maintain communications, the Quartermaster to furnish clothing and food, or the Engineers or Construction Battalions to reconstruct utilities, and clear roads and bridges.

13.12. It is apparent therefore that each technical or service branch in the Army, each bureau in the Navy, and each command in the Air Force, as well as its field activities and troop or fleet units, should examine the impact of atomic warfare on its ability to fulfill its assigned major functions and responsibilities. It is obviously beyond the scope of this volume to propose a solution, in each case, to the problem of recovery from atomic attack. For any specific installation or unit, it is the responsibility of the comanding officer and the duty of his advisers to familiarize themselves with the special defense problems involved, to review available defense measures, and from those measures to develop a standard operating procedure for defense, based on the particular requirements of the command concerned.

Atomic Defense Personnel

13.13. The training and functions of specialist personnel required for atomic defense at the various military echelons are summarized below. The titles as shown represent functions rather than specific service positions, as these positions may be assigned different nomenclatures in the three Services. The word "radiological" which occurs in the titles derives from the fact that the principal *additional* specialist personnel required in atomic defense are those trained in the problems presented by radiation following a contaminating attack. It should not be permitted to give any implication that the radiological hazard will be the principal one ordinarily encountered as a result of atomic warfare.

Radiological Defense Engineers

13.14. These officers are the highest level staff advisers. Their training ordinarily includes postgraduate studies in nuclear science, and in the military use of atomic energy, as well as instruction in certain specialized aspects of atomic defense. They are normally assigned to the following (or higher) staff levels: Fleet Commander, Theater Army Command, and major Air Force Command. They will act as advisors to their commanders on all matters pertaining to the defensive aspects of atomic or radiological warfare (except medical aspects), and will provide technical advice to subordinate organizations.

Radiological Medical Officers

13.15. These are medical officers with special detailed training in the field of radiobiology, radiation hazards, and treatment of radiation casualties, and are assigned at the same level as the Radiological Defense Engineers. They will be responsible for advising the commander on all medical aspects of radiological defense, and for providing technical advice to subordinate organizations.

Radiological Defense Officers

13.16. These are usually graduates of special 6-week courses in radiological defense, which include some instruction in basic nuclear science, and defense planning and procedures (fig. 13.16). These officers are assigned to staff levels subordinate to those served by the Radiological Defense Engineers. They advise their commanders in all matters pertaining to radiological defense (except medical aspects), aid in preparation of organizational defense plans, and direct and/or conduct the training of unit personnel such as survey, monitor, and decontamination teams.

Radiological Officers (Medical)

13.17. These are medical officers who have received a short course in the special effects of radiation, as it applies to the health and efficiency of military personnel, and the treatment of radiation casualties. These officers will be assigned at the same staff levels as the Radiological Defense Officers, and will advise their commander on all medical aspects of radiological defense.

13.18. The categories listed above are largely staff advisers, although they may be called upon, on occasion, to participate actively in defense operations. The present plans of the respective Services indicate that the duties, training, and staff level of these officers will be approximately parallel.

13.19. The following specialists in the unit organization should be, for the most part, enlisted personnel, though it may often be found desirable to qualify junior officers for more critical supervisory

Figure 13.16. Student Radiological Defense Officers obtaining calibration data for radiac instruments.
(The small cylinder suspended in the center is a radium source of known strength.)

positions. While nomenclature may differ among the services, these specialists may be described by general functions performed, as follows:

Radiological Monitors

13.20. These men are trained in monitoring as an additional duty. They are taught the principles of protection against radiation hazards, and survey techniques with radiac instruments. They will receive special training in monitoring problems peculiar to the equipment and functioning of their units.

Matériel Decontamination Teams

13.21. These are unit personnel trained in the elements of radiological decontamination operations. They are locally trained by the unit Radiological Defense Officer. Their training should include decontamination operations in general, with specific training in decontamination problems peculiar to the equipment of the unit to which they belong.

Personnel Decontamination Teams

13.22. These usually are medical enlisted personnel who have received special training by the Radiological Defense Officer and unit medical officers in detecting and removing contamination from individuals, and in the operation of personnel decontamination facilities, e.g., change stations or equivalent field facilities.

Dosimetry Technicians

13.23. These are medical enlisted personnel trained, usually in special schools or courses, to evaluate the degree of exposure of individuals from standard dosimeters, film badges, and similar devices.

Radiac Instrument Repairmen

13.24. These will normally be regular electronics personnel who have received special training in the repair and maintenance of radiac instruments. As pointed out in chapter 8, these instruments present some specialized problems which the ordinary electronics technician may not be prepared to handle without some additional training.

13.25. The foregoing enlisted specialists are usually required only in operating units, though qualified individuals may be needed occasionally on staff levels.

ARMED FORCES ORGANIZATION FOR ATOMIC DEFENSE

General Considerations

13.26. Though certain general similarities of function and procedure throughout the Armed Forces have been discussed, each service must be treated individually in a description of specific organizations. Variation in the atomic defense organization of the services is a natural result of their divergence in function; for example, widely different defense problems are presented by a ship at sea, an operational airbase, and a troop training center. In spite of the difference in function, however, the specialists described in the preceding section, manning key positions in the atomic defense organization, require essentially the same specialized training. Therefore, though the previous professional military backgrounds of these specialists will vary widely, in radiological matters they will have received approximately identical training, and can communicate intelligibly with individuals holding corresponding positions in other Services. This is essential now and in the future, with the steadily increasing tendency toward closer operational interdependence between Services.

13.27. One of the assigned responsibilities of the Armed Forces Special Weapons Project is the furthering of the development, within the Armed Forces, of defensive measures against atomic weapons through such means as: (1) coordination and support of training for defensive measures where joint service programs are desirable, (2) evaluation of weapons effects data and dissemination of results of such evaluations to the Services and also to other governmental agencies where appropriate, (3) coordination of military research and development in the field of radiac instruments, individual and collective protective devices, radiological decontamination procedures, and medical aspects of atomic warfare, in accordance with the policies of the Research and Development Board.

13.28. The relationship of the Armed Forces Special Weapons Project to the Department of Defense and other agencies of the Federal Government, the Atomic Energy Commission in particular, in matters of the military application of atomic energy is shown in the chart in table 13.28.

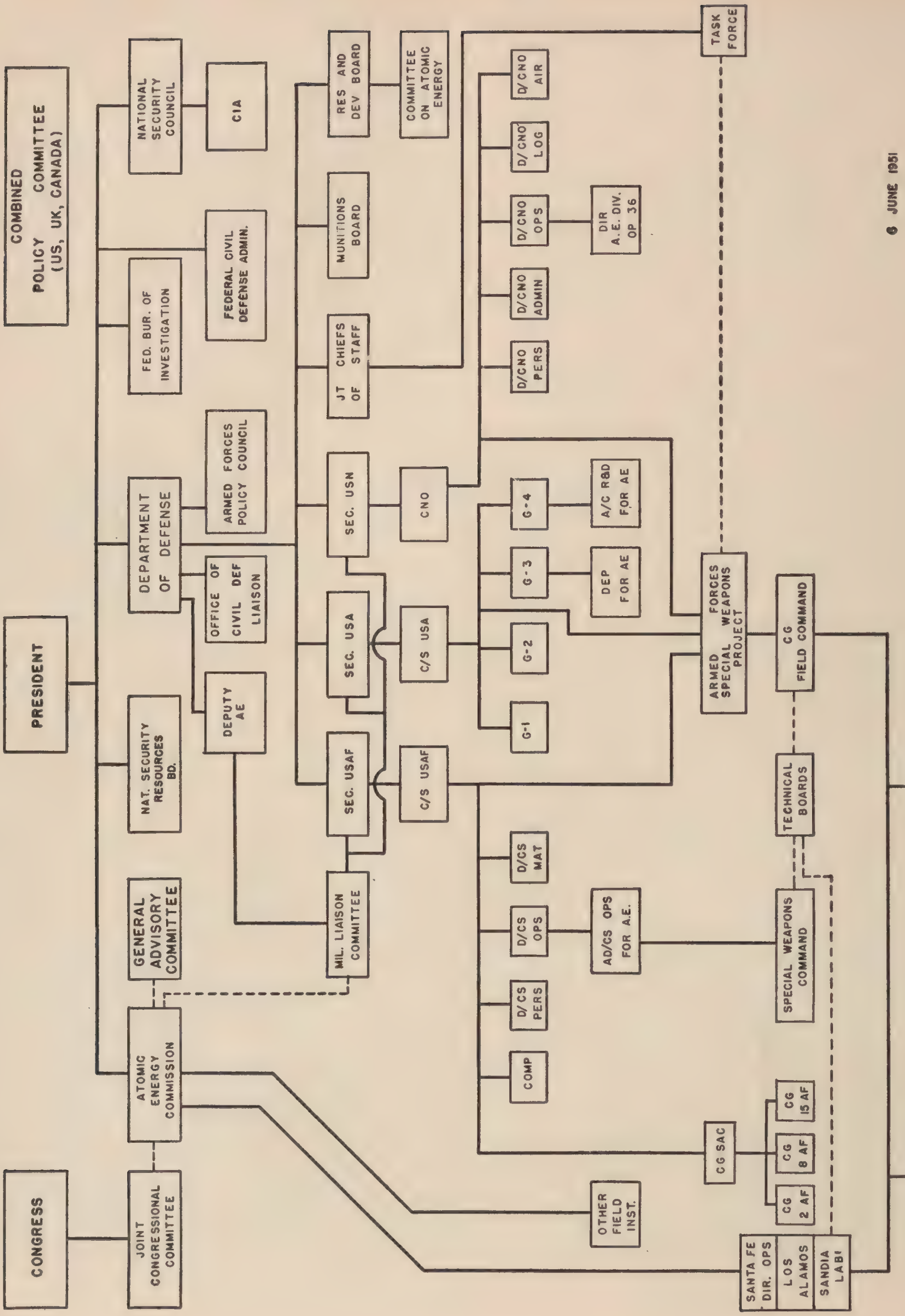


Table 13.28. Organization for Military Application of Atomic Energy.

Department of the Army Atomic Defense Program

13.29. The General Staff, United States Army, is responsible for formulating and promulgating the over-all atomic defense program of the Department of the Army. Specific responsibilities have been subassigned to technical agencies as set forth below.

13.30. To deal with the special problems associated with radiological defense, various branches have been charged with the duties summarized here. It will be seen that existing organizations assume responsibility for those elements of the radiological defense program for which they are particularly equipped by experience.

a. The Chemical Corps

(1) Development and supervision of the Army radiological defense organization.

(2) Preparation, coordination, and supervision of radiological defense training programs, with the exception of medical aspects.

(3) Furnishing technical information and advice necessary to training, except in those fields specifically assigned the Surgeon General, the Chief Signal Officer, the Chief of Engineers, etc.

(4) Assisting the Chief, Army Field Forces, in developing tactical radiological information for the Field Forces, and in training unit radiological personnel.

(5) Formulation of defensive radiological doctrine for all elements of the Department of the Army.

(6) Conducting research and development in radiological decontamination methods and equipment, and individual and collective personnel protection methods and devices.

b. The Army Medical Service

(1) Preparation of policies to apply within the Department of the Army for diagnosis, treatment (including patient decontamination), evacuation, and hospitalization of radiation casualties.

(2) Administration of dosimetry operations and records as an integral part of the individual medical record system, and medical statistical reporting system.

(3) Training necessary Army Medical Service personnel in the medical aspects of atomic warfare, and the treatment of radiation casualties.

c. The Signal Corps

(1) Training electronic instrument maintenance personnel in field and base maintenance of radiac instruments.

(2) Preparation and dissemination of instructions for storage, care, and use of electronic radiac instruments.

(3) Conducting research and development in methods of radiation detection. Development and procurement of radiac instruments.

d. The Corps of Engineers

(1) Design and construction of protective structures capable of withstanding atomic attack.

(2) Development and procurement of equipment for purifying radiologically contaminated water.

(3) Conducting research and development on equipment, or the modification of existing equipment, for the recovery of contaminated land areas and installations.

e. The Quartermaster Corps

Procurement and distribution of special (protective) clothing for radiological operations.

13.31. Radiological defense organization in the Army tactical unit is shown in table 13.31. Although this chart begins at Army level, it can be extended upward to Army Group, and to Theater of Operations Headquarters.

13.32. Radiological defense organization for a normal static Army installation is represented in table 13.32. This organization may differ widely in detail from one installation to another, but in essentials it will be as indicated.

Department of the Navy Atomic Defense Program

13.33. Within the Department of the Navy, the program of atomic defense has been distributed among the Bureaus, and Commanders and Commandants afloat and ashore. The Chief of Naval Operations exercises policy control in the fields of organization, equipment and personnel qualifications, assignment and training. The division of responsibilities is as follows:

a. Bureau of Aeronautics

(1) Development and procurement of airborne radiac equipment.

Table 13.31. Army Tactical Unit Organization

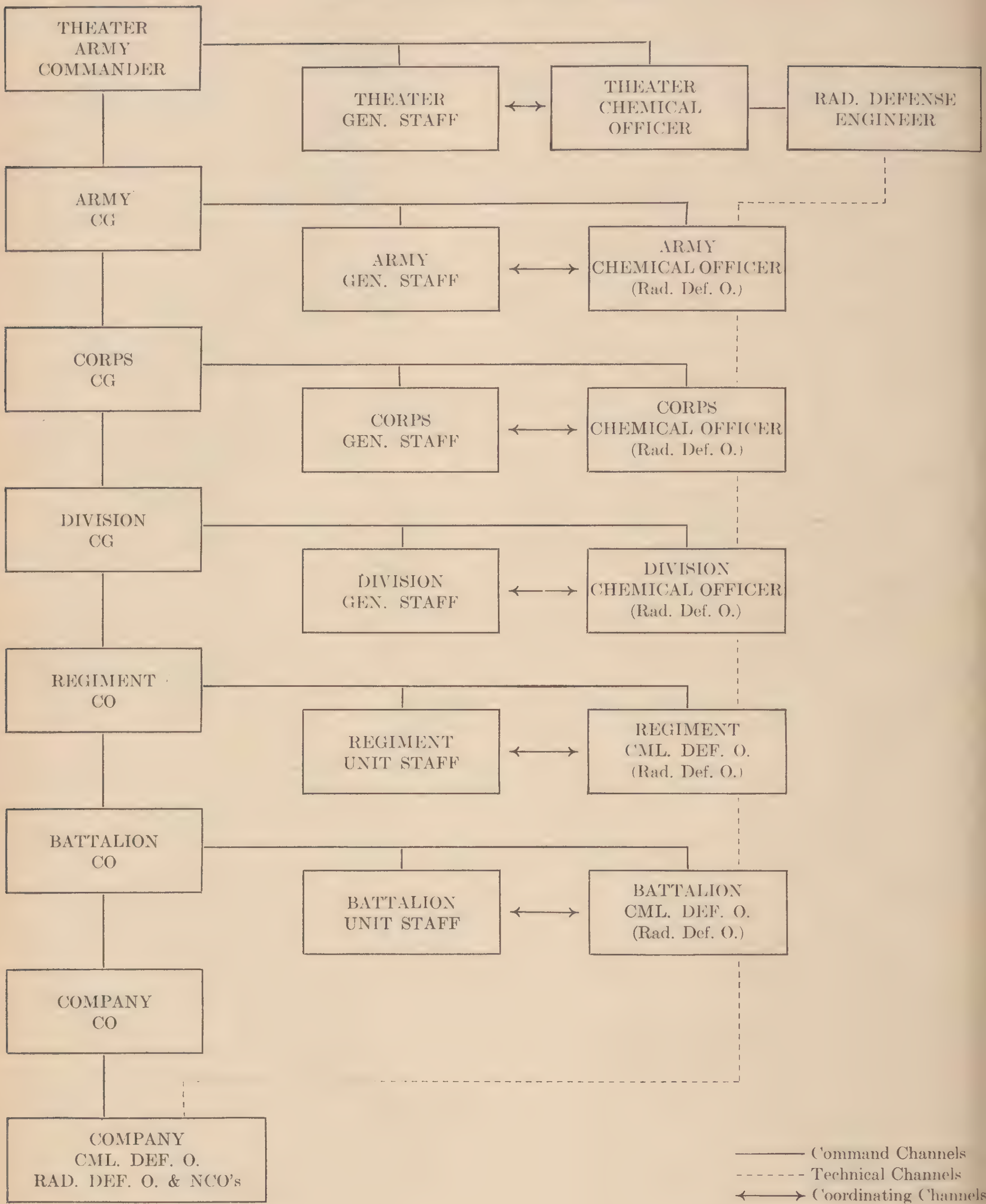
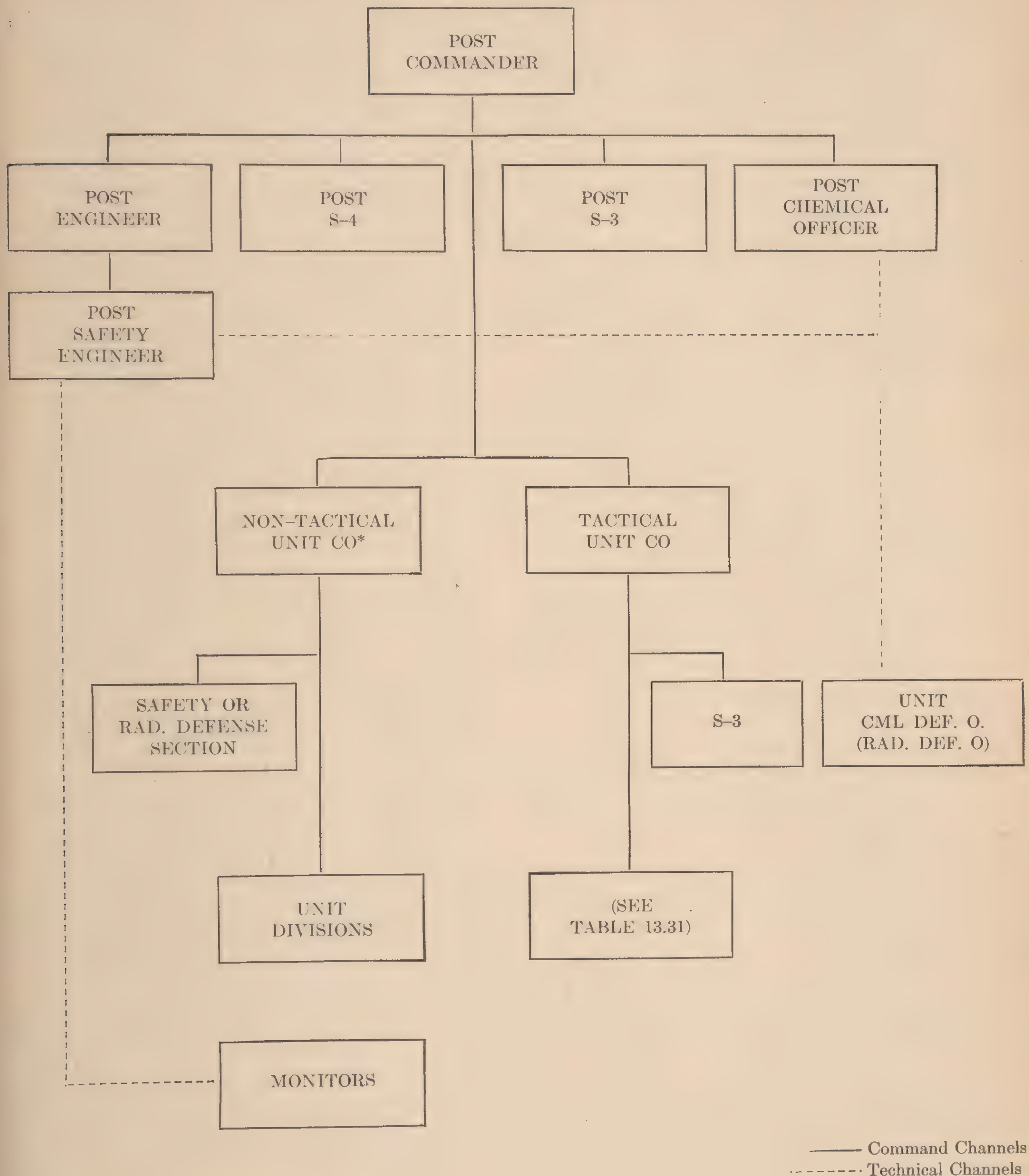


Table 13.32. Army Base Organization



*School; technical, logistical or industrial unit; etc.

(2) Development of equipment and methods for individual and collective protection of personnel in aircraft.

(3) Development of equipment and methods for radiological decontamination of aircraft.

(4) Development of materials for increasing the resistance of aircraft to thermal radiation.

(5) Investigation of the ability of aircraft to withstand blast pressures and thermal radiation and the establishment of recommended operational limits.

b. Bureau of Medicine and Surgery

(1) Development of procedures and development and provision of equipment for treatment of mass casualties resulting from burns, mechanical injuries, or radiation.

(2) Establishment of radiation tolerances and regulations and provision of information on the physiological effects of exceeding such tolerances by varying amounts.

(3) Development of methods for treatment of radiation casualties.

(4) Advising the agencies responsible for the development of radiac instruments on specifications for such instruments.

(5) Investigation of means of increasing the resistance of individuals to thermal and ionizing radiation.

c. Bureau of Naval Personnel

(1) Establishment of training and educational programs and conduct of schools.

(2) Establishment and promulgation of qualification standards for personnel performing atomic defense duties.

d. Bureau of Ships

(1) Investigation of the effects of atomic explosion on ship structures and equipment and modification thereof where indicated and practicable.

(2) Development and procurement of radiac instruments, except airborne instruments.

(3) Development and procurement of equipment for individual and collective protection of personnel on shipboard.

(4) Development of methods and development and procurement of equipment for decontamination of ships.

(5) Investigation of radiological contamination and decontamination and thermal radiation phenomena and provision of basic data to other agencies for development, application, and procurement.

(6) Study of the interrelation of various atomic weapons countermeasures and provision to other agencies of data necessary for planning.

e. Bureau of Supplies and Accounts

Development of methods for the protection of supplies in storage and in transit and for their decontamination.

f. Bureau of Yards and Docks

(1) Development of and procurement of equipment for individual and collective protection of personnel ashore.

(2) Development of methods and equipment for radiological decontamination ashore.

(3) Modification of fire fighting, clean-up and demolition techniques as necessary to combat large scale damage.

(4) Where practicable, incorporation of protective features in new and existing structures to improve their resistance to blast, earthshock, fire and radiological contamination and to simplify decontamination.

g. Commanders afloat, Commandants of Naval Districts and River Commands, and Naval Base Commanders

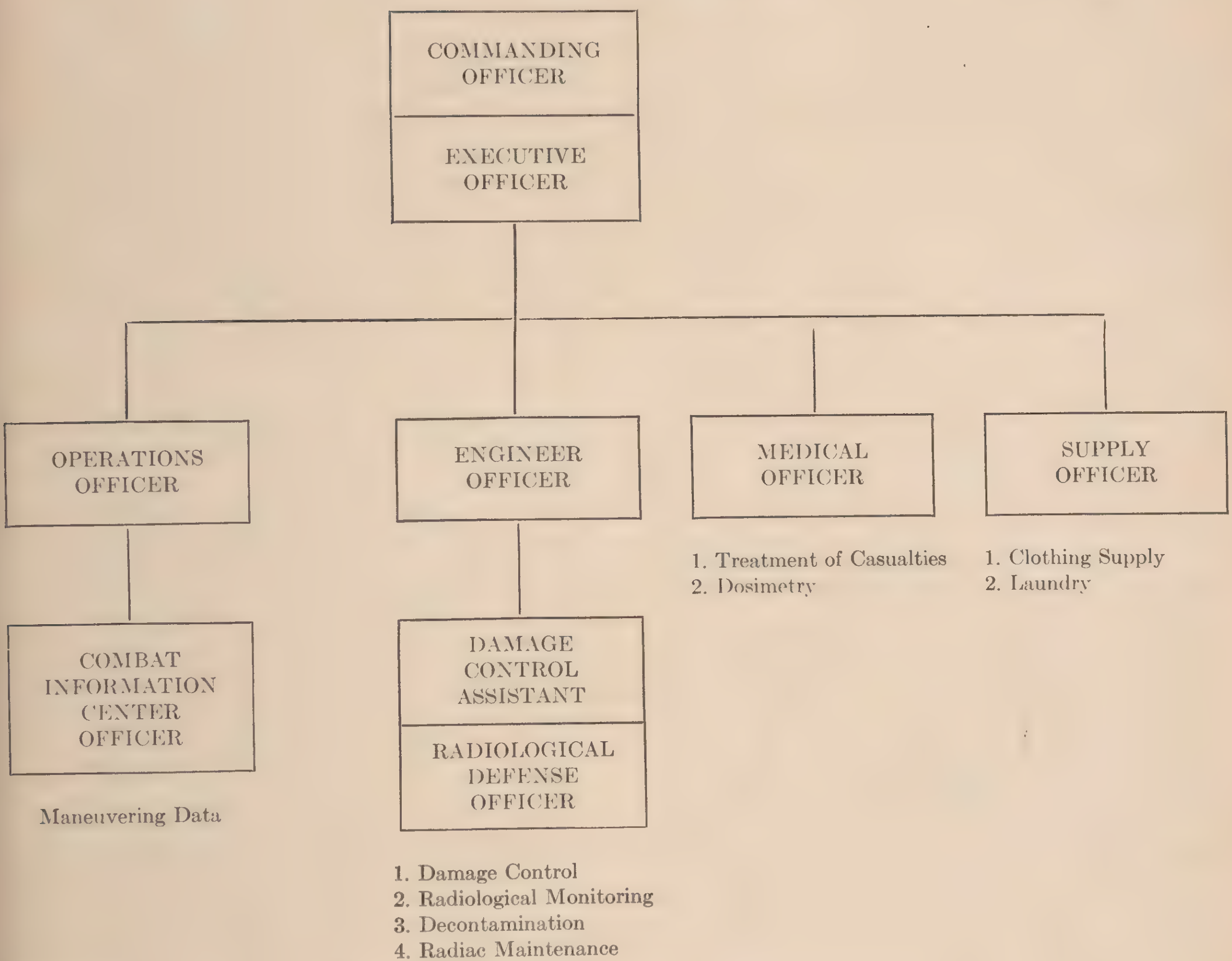
(1) Establishment of policies for and exercise of control over defense preparation of subordinate commands to ensure a high degree of readiness for individual and mutual defense.

(2) Coordination of the execution of defensive measures in time of attack.

13.34. So far as possible, the atomic defense program of the Navy holds to the principle of using existing organizations to carry out atomic defense measures. Afloat the Damage Control organization is used, while the Disaster Control organization is responsible for this function ashore. Tables 13.34*a* and 13.34*b* show how atomic defense fits into the over-all passive defense setups of ships and shore stations respectively.

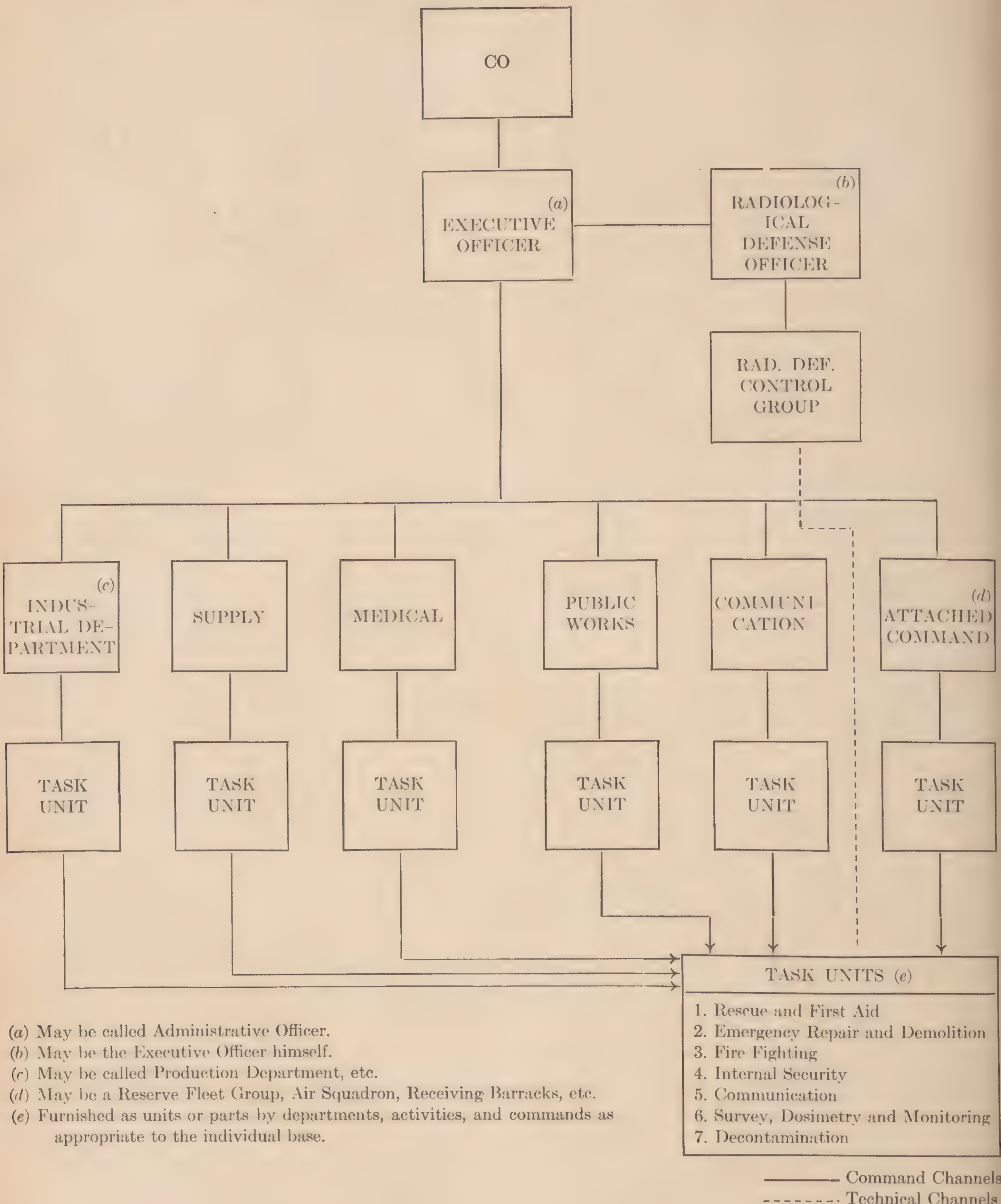
13.35. Complicated as they may seem, these organizational charts indicate a much clearer division of responsibility than can or should exist in practice. The Radiological Defense Officer, afloat, serves under or may be the Damage Control Assistant. He must be familiar with all aspects of damage control,

*Table 13.34a. Navy Afloat Organization**



*This chart shows only those parts of the ship's organization which are directly concerned with atomic defense.

Table 13.34b. Organization of Navy Shore Installation



(*a*) May be called Administrative Officer.
(*b*) May be the Executive Officer himself.
(*c*) May be called Production Department, etc.
(*d*) May be a Reserve Fleet Group, Air Squadron, Receiving Barracks, etc.
(*e*) Furnished as units or parts by departments, activities, and commands as appropriate to the individual base.

particularly with the place and relative importance of radiological defense in the over-all problem.

13.36. The Radiological Defense Officer at shore installations has the same general relationship to the organization as his counterpart afloat. The basic difference, as may be seen in table 13.34b, is that his position is that of an adviser to the Executive Officer or Commanding Officer.

Department of the Air Force Atomic Defense Program

13.37. The Air Force concept of atomic defense is a part of the broader Passive Defense System. As used here, the term Passive Defense refers to measures taken to prevent or minimize casualties and damage resulting from attack with atomic, biological, chemical, or conventional weapons. It includes such other actions as would be required to permit continuation or restoration of vital operations at Air Force installations.

13.38. The organization for Passive Defense involves every individual in the Air Force and it is essential that each contribute his maximum effort, both individually and collectively. To achieve the maximum effective utilization of personnel, the Passive Defense activities will be incorporated into the existing Air Force organizational structure. These activities will be centrally controlled and integrated into a basic plan to be developed and implemented as the situation requires. This will necessitate assignment of various personnel to additional duties in Passive Defense.

13.39. An Air Force Officer specialty, Passive Defense Officer, will be established to assist Air Force commanders in carrying out their responsibilities as outlined in this chapter. Officers with SSN 7332, Rad. Def. Officer, and 4591, Special Munitions Officer, are currently most nearly qualified for this position and will be utilized to the extent available. Resident school courses will be established to provide complete qualifications. Assignment and authorization of Passive Defense Officers will be in accordance with normal manning guides and procedures.

13.40. Headquarters of the Air Force will be responsible for broad planning and policy guidance in connection with Passive Defense. It will issue personnel and equipment authorizations, and will establish a research and development program.

13.41. The general responsibilities of the major Air Commands, with respect to Passive Defense, will be to guide in formulating and subsequently reviewing plans for the lower echelons of the Command. They will also monitor and review the education and training for their lower echelons.

13.42. In addition, the major Air Commands have been assigned specific responsibilities as follows:

a. Air Research and Development Command
Research and development of methods and equipment.

b. Air Matériel Command
Procurement, issue, and depot maintenance of equipment and materials.

c. Air Proving Command
Operational suitability testing of equipment.

d. Air Training Command
In residence training in Passive Defense specialties.

13.43. The Air University will give proper emphasis on Passive Defense in its courses, and will conduct appropriate investigation and studies. The Air University also will be responsible for the preparation of such publications pertaining to Passive Defense as directed by Headquarters of the Air Force.

13.44. An Air Base or comparable unit will be responsible for the formulation of a Passive Defense plan, including personnel indoctrination. Detailed material for formulation and implementation will be included in an Air Force Manual on Passive Defense.

13.45. The organization chart for Passive Defense of a typical USAF wing is given in table 13.45. The various duties of the Passive Defense units, composed of additional duty personnel, are indicated.

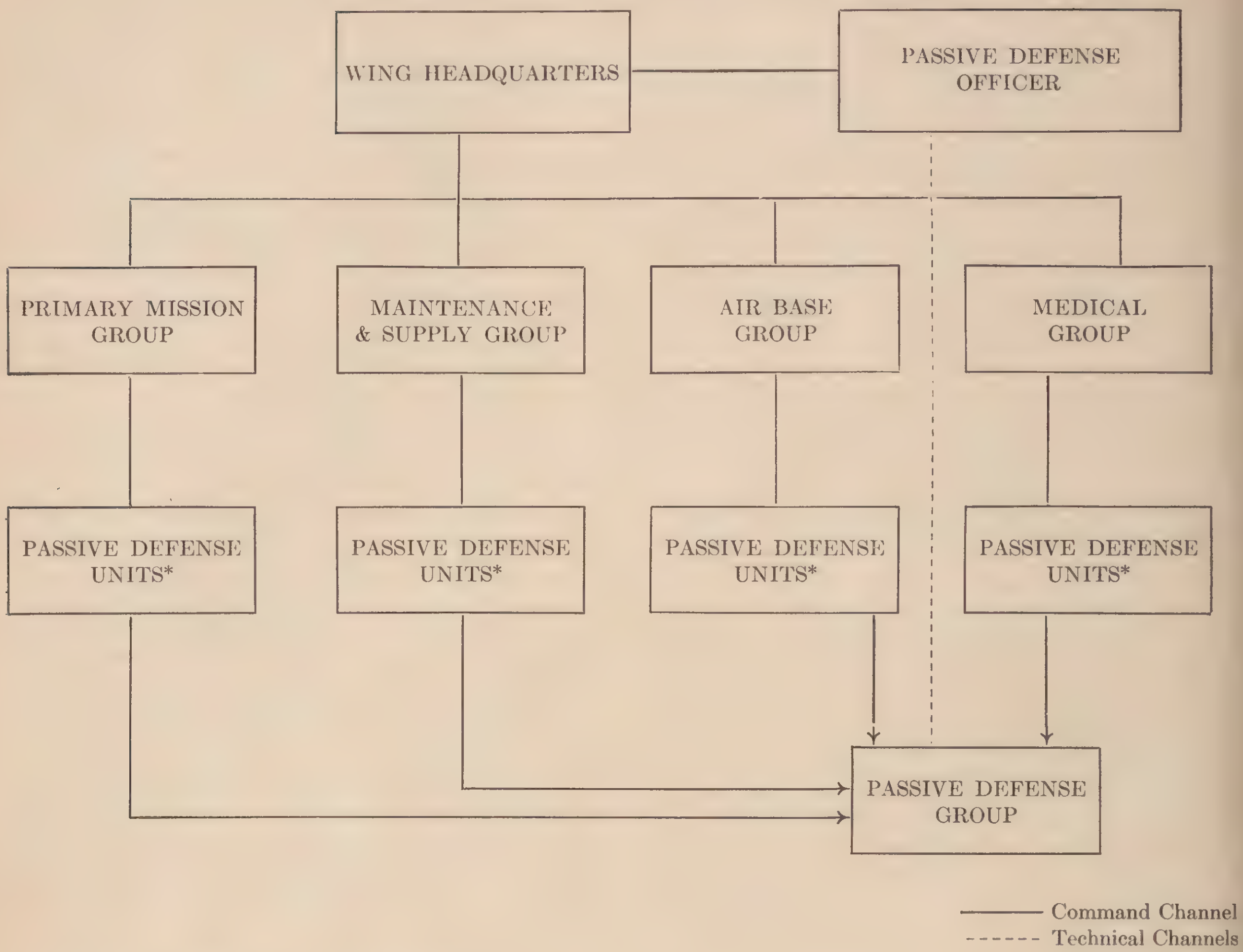
TRAINING FOR ATOMIC DEFENSE

General Principles

13.46. Directives issued by the Army, Navy, and Air Force specify in detail the nature and amount of training in atomic defense to be given to personnel in general, and to specialists who form part of the radiological defense organization. There are, however, certain broad principles applicable to training in atomic defense in all three Services, which should be recognized and applied.

13.47. Special emphasis should be given to the indoctrination and training of commanders and poten-

Table 13.45. Organization of USAF Wing for Passive Defense



Responsibilities of Passive Defense units include:

1. Rescue and First Aid
2. Fire Suppression
3. Police Action
4. Internal Security
5. Communication
6. Emergency Repair
7. Survey, Monitoring, Dosimetry
8. Decontamination

---

*Passive Defense units composed of additional duty personnel.

tial commanders at all echelons. General courses in radiological defense are offered at several schools. Senior officers in responsible positions who find it difficult to attend such courses should take advantage of all training literature, trained assistants, and such other opportunities as are available to prepare themselves to meet the implications of atomic warfare. Many commanders may be deterred by the overtechnical approach of some early training publications on the subject; however, it is not necessary to be qualified in nuclear science before undertaking a study of atomic warfare. The effects, as stated at the opening of this chapter, differ chiefly in magnitude from those long familiar as a part of aerial warfare, and study can begin there.

13.48. All personnel should receive sufficient basic training in atomic defense, beginning with simple instruction in basic bomb effects, i.e., blast, heat, and radiation, and how and when evasive action is possible. This will lead to the elements of individual protection, use of protective equipment, and radiac instruments, principles of decontamination, of personnel and equipment, and conduct in a contaminated area.[1] Finally, the part each individual must play in the radiological defense of his unit must be taught him. Throughout this basic training, indoctrination should emphasize the point that the atomic bomb is a potent weapon and a most spectacular one but, after all, it is just another form of attack and, as always, the trained men usually survive, while the untrained do not.

13.49. Such basic training should receive its due emphasis, being repeated periodically until the unit is considered adequately trained. A program of immediate indoctrination for replacement personnel should supplement the basic program.

13.50. The training of the necessary radiological defense specialists in any unit will take officers and men away from their normal work for extended periods, whether the training is undergone on the unit installation proper, or at a service school. There is a strong tendency in many units, particularly under wartime conditions, to send to school those individuals who can be most readily spared, rather than those qualified by background and occupation of a critical position in unit organization. This tendency should be rigidly curbed.

13.51. Training alternates for key positions in the radiological defense organization must not be overlooked. This is as important in small units as in large. Training for an alternate Radiological Defense Officer, for example, can be largely on-the-job training if necessary, but provision for such an alternate always must be made.

Drills and Practice Alerts

13.52. Once training of general and special personnel has reached a satisfactory level, it should be kept there by reasonably frequent drills. These can be of a skeleton variety in which only the specialists function to meet assumed situations, or they can take the form of exercises in which all personnel participate. The latter form is especially valuable in that disaster planning is then carried fully beyond the paper level. Action is actually taken, and any weaknesses in planning may be revealed in the process. Unit personnel will function far more efficiently under disaster conditions if procedures have been rendered familiar by practice alerts.

13.53. After initial training in individual units reaches a working level, drills and practice alerts should be coordinated so that all personnel of a command or installation participate. In planning these exercises, experience has shown that it is especially important that all of the proposed means of emergency communication, such as portable radios, should be given a thorough test under realistic conditions. In addition to revealing possible communications difficulties and pointing the way to their correction, these general drills will help insure the over-all cooperation essential to the effective rendering of mutual aid under emergency conditions.

[1] See appendix III for list of publications and motion picture films available for this purpose.

SUMMARY

Except for their much greater magnitude, the problems presented by atomic attack are, in many respects, similar to those due to conventional saturation attacks. Although nuclear radiation is a new feature of warfare, the methods of dealing with radioactive contamination involve the same principles as are used for chemical decontamination.

The conduct of atomic defense requires no important change in the present military structure, although some additional training in radiological matters is necessary for specialist personnel.

An atomic attack will probably saturate the defense capabilities of a military unit or installation. Hence, mutual aid is a vital aspect of planning for atomic defense. Such planning should be as specific and detailed as circumstances permit.

Responsibility for various aspects of the radiological defense program, as a part of atomic defense, is distributed among the technical and service branches of the Army, the bureaus of the Navy, and the commands of the Air Force. Each of the existing organizations will deal with those elements of the program for which it is particularly qualified.

Special emphasis should be given to the indoctrination and training in radiological defense of commanders and potential commanders at all echelons. All personnel should receive some training in atomic defense, including bomb effects and evasive action. Frequent drills and practice alerts are desirable if atomic defense activities are to function efficiently under actual disaster conditions.

CONCLUSION

There has been a tendency to attach too much of an element of mystery to atomic weapons and their effects. It is hoped that this book has helped to dispel any such feeling which may have been in the minds of some of its readers. Familiarity with the probable effects of new weapons is an important first step in planning how to deal with them under various conditions. In the case of atomic weapons, most of these effects are known to our Armed Forces from previous wartime experience with other explosives, so that the difference is principally one of degree. Even the nuclear radiation, although not heretofore encountered in military weapons, is similar in many respects to chemical warfare from the standpoint of defensive measures.

No radical changes in organization are required for military defense against atomic weapons; only a few minor changes and additions in specialist personnel are necessary. Much of the equipment needed has already been provided for other purposes; the balance is being rapidly supplied. The remaining—and continuing—task is to achieve a proper level of indoctrination and training in the field, and to observe whatever defensive precautions are consistent with the military situation.

Appendix I

SCALING LAWS FOR ESTIMATING BLAST, THERMAL, AND IMMEDIATE NUCLEAR RADIATION EFFECTS FOR ATOMIC BOMBS OF DIFFERENT ENERGIES

A.1. A number of figures are appended here which will permit fairly accurate scaling estimates to be made rapidly. They give the peak overpressure on the ground due to an air burst (fig. A.1a), the thermal energy received (fig. A.1b), and the immediate nuclear (gamma) radiation dose (fig. A.1c), respec-

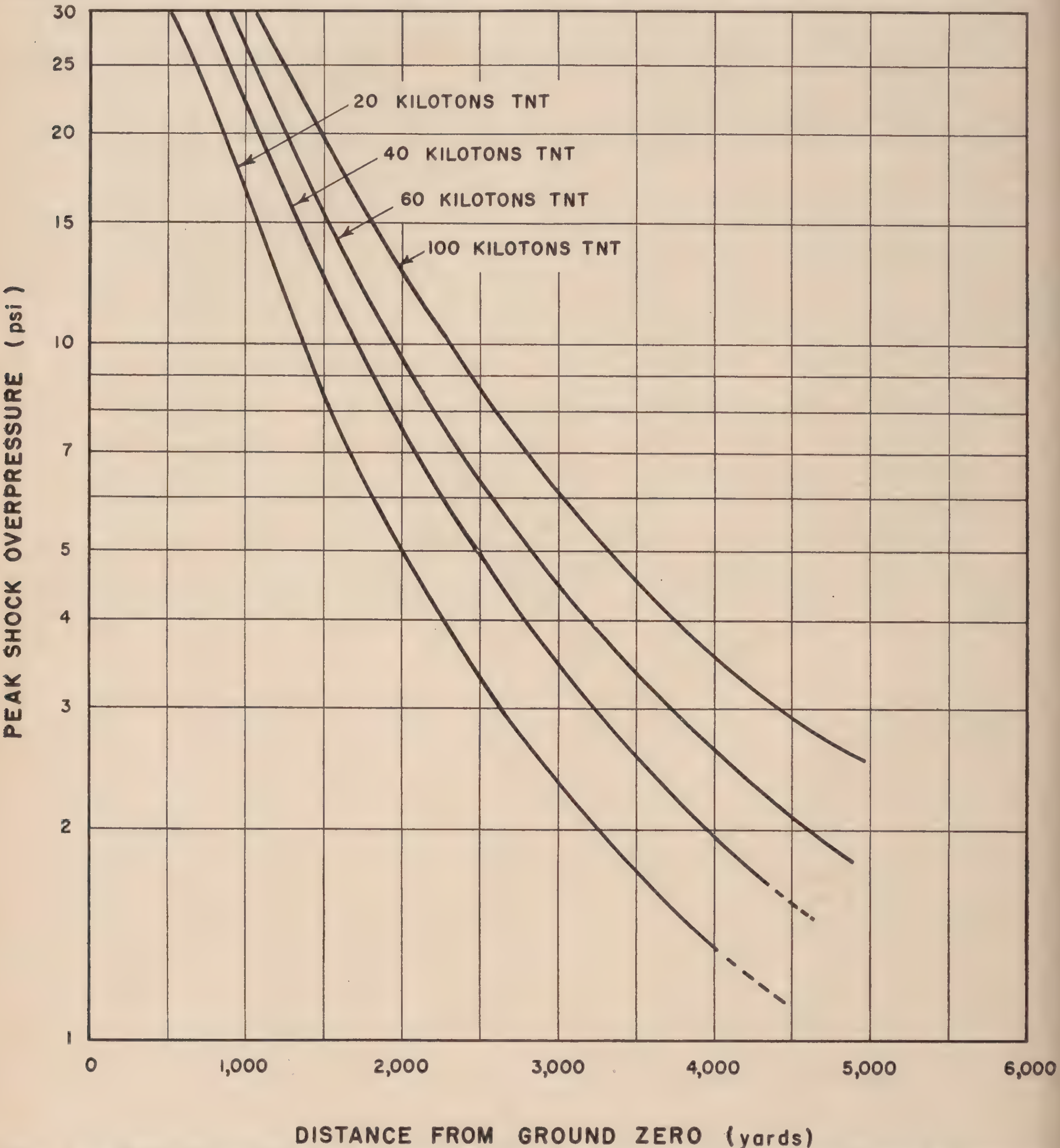


Figure A.1a. Scaling for blast from atomic air bursts. Variation of peak overpressure on ground with distance from ground zero.

tively, at various distances from ground zero, for bombs of different energies. It should be noted that in figure A.1b, the ordinates are thermal energies, in calories per sq. cm., divided by the kiloton TNT energy equivalent of the bomb, i. e., the thermal energy per kiloton TNT of bomb energy. To obtain the results for a bomb of energy equivalent to W kilotons TNT, the ordinates are multiplied by W.

Example: What would be (i) the peak overpressure; (ii) the thermal energy on an average clear day; and (iii) the immediate nuclear radiation dossage, at a point 2,000 yards from ground zero, due to the air burst of a 60-kiloton TNT equivalent atomic bomb?

(i) From figure A.1a, using the curve marked "60 kilotons TNT," the peak overpressure at 2,000 yards is seen to be about 9.5 psi.

(ii) The thermal energies received on an average clear day may be regarded as being roughly mid-

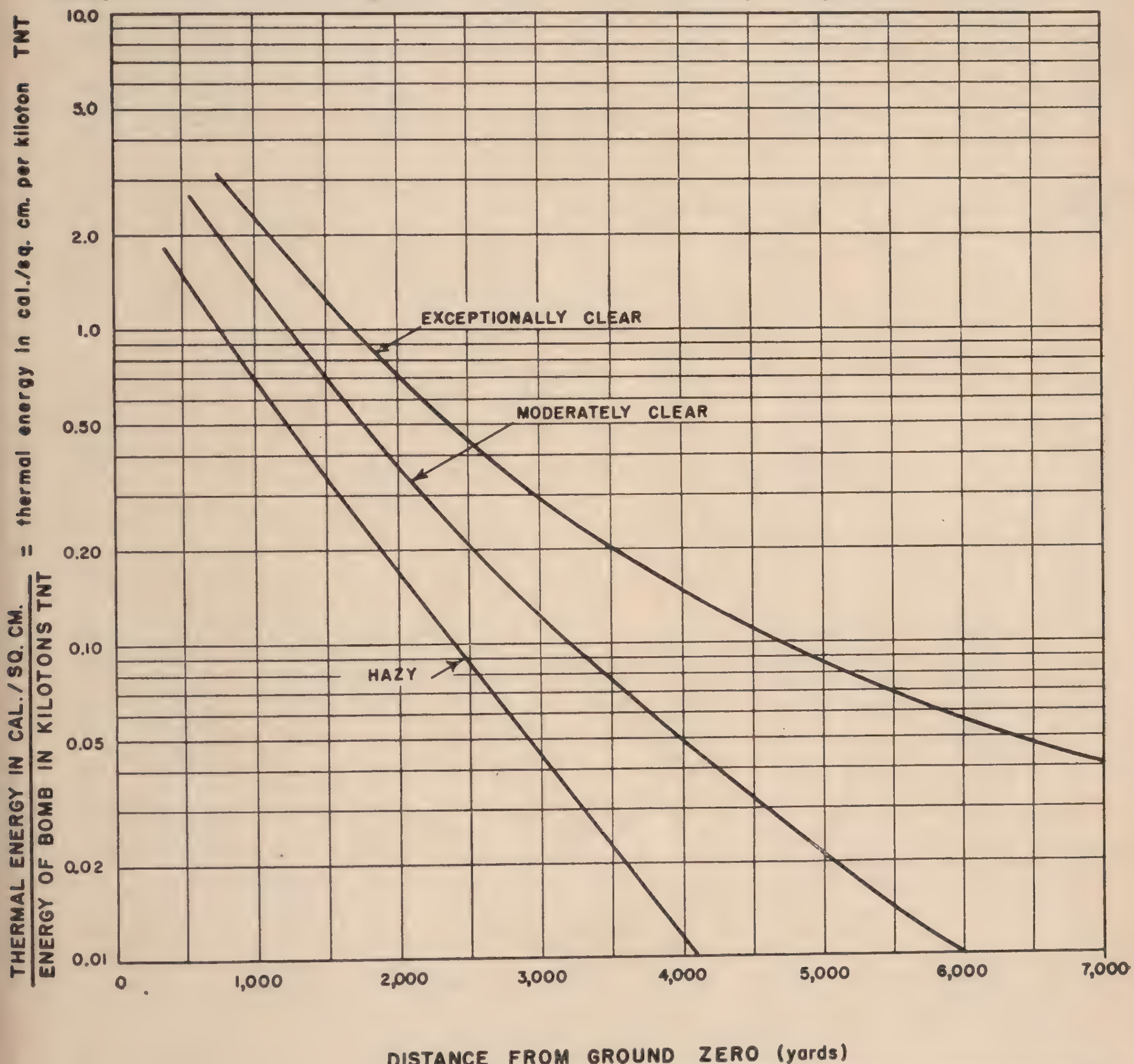


Figure A.1b. Scaling for thermal radiation from atomic air bursts. Variation of thermal energy received with distance from ground zero for different states of the atmosphere.

way between those for the curves marked "moderately clear" and "exceptionally clear." The ordinate of figure A.1b corresponding to a distance of 2,000 yards, is thus found to be about 0.5 cal./sq. cm. Upon multiplying by 60, which is the kiloton TNT equivalent of the bomb, the result is 30 cal./sq. cm. as the energy received.

(iii) From figure A.1c, using the curve marked "60 kilotons TNT," the immediate nuclear radiation dose at 2,000 yards is seen to be 66 roentgens.

Example: What is the limiting distance from ground zero at which moderate skin burns would be experienced on an average clear day as the result of the air burst of a 30-kiloton TNT equivalent bomb?

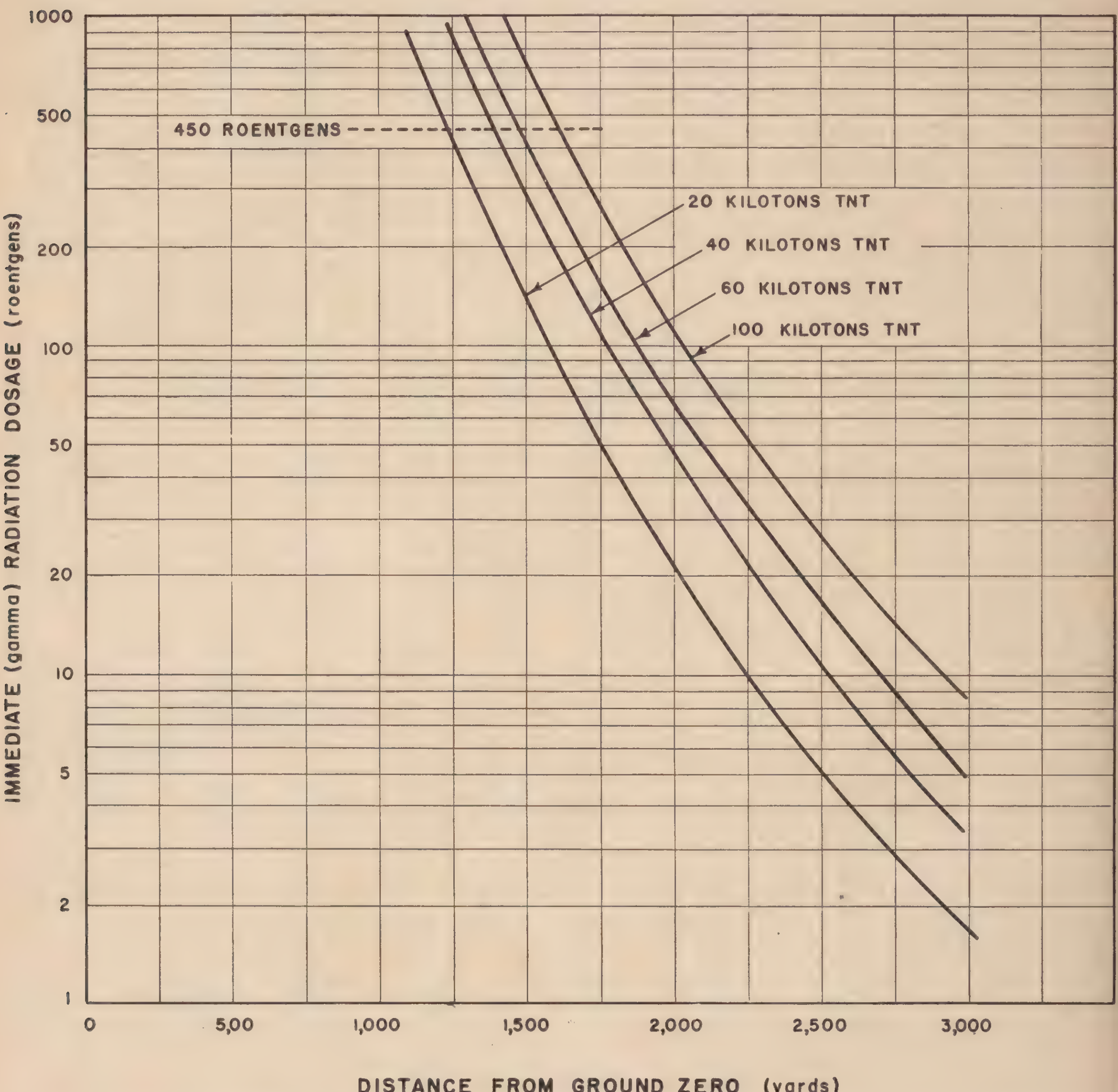


Figure A.1c. Scaling for immediate nuclear radiation from atomic air burst. Variation of total radiation dosage with distance from ground zero.

The thermal energy required to produce moderate skin burns is 3 cal./sq. cm., and this divided by 30, the kiloton TNT equivalent of the bomb, is 0.1. The ordinate 0.1 in figure A.1b for an average clear day, i. e., between "moderately clear" and "exceptionally clear," corresponds to a distance of 3,750 yards from ground zero. This is the required limiting distance.

A.2. Some of the scaling data have been plotted in a simpler manner in figure A.2. While this is less complete than the figures given above, it is simpler to use. It should be noted that the thermal radiation curves refer to an average clear day.

Example: At what distance from ground zero would the air burst of a 100-kiloton TNT equivalent bomb produce (i) a peak overpressure of 5 psi on the ground; (ii) 3 cal./sq. cm. of thermal radiation on a clear day; (iii) 450 roentgens of immediate nuclear radiation?

(i) The estimated distance for 5 psi, obtained by interpolation between the curves "3 psi" and "10 psi," is about 3,500 yards, for a 100-kiloton TNT bomb.

(ii) From the curve for "3 cal./sq. cm." of thermal radiation, the distance is found to be about 6,000 yards.

(iii) The curve "450 roentgens" indicates that the distance would be approximately 1,650 yards.

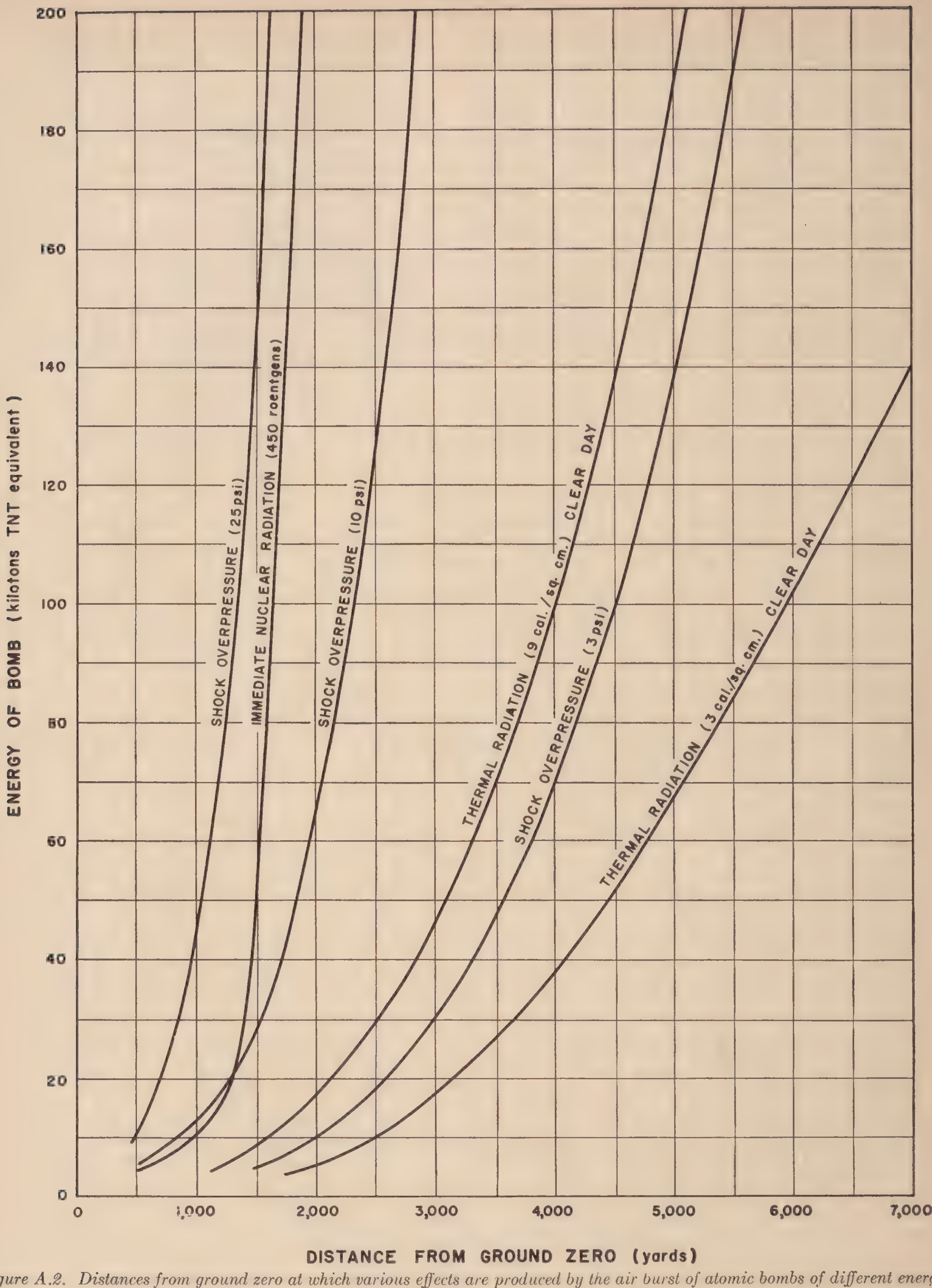


Figure A.2. Distances from ground zero at which various effects are produced by the air burst of atomic bombs of different energies.

Appendix II

COMPUTATION OF DOSAGES PRODUCED BY RADIOLOGICAL CONTAMINATION RESULTING FROM AN ATOMIC EXPLOSION, AND DETERMINATION OF ALLOWABLE STAY TIMES

B.1. By plotting the formula in par. 2.26 on a log-log scale, the result is a straight line giving the variation with time of the radiation intensity due to *fission products* at any given place, as illustrated in figure B.1 on the opposite page. The parallel lines are for various values of R_1, the radiation intensity (or dose rate) at 1 hour after the explosion. From this figure the dose rate at a specified time may be estimated if that at any other time is known. The time required for the dose rate to decrease to a certain value can also be found. Some of the uses of figure B.1 are illustrated by means of the following examples:

Example (1a). At $1\frac{1}{2}$ hours after an atomic explosion the radiation dose rate at a certain place, due to fission products, was found to be 8 roentgens per hour. What would it be after 24 hours?

The arrow (1) in figure B.1*a* indicates the time "$1\frac{1}{2}$ hours" after the explosion, and arrow (2) shows the dose rate "8 roentgens per hour." These lead to the point marked *a*, which represents the information given. A line through *a*, parallel to the others in the figure, will then indicate the change of radiation intensity with time at the place under consideration. The dose rate at 24 hours after the explosion is found by following this line from *a* to *b*, where it meets the vertical line for "24 hours" after the explosion, indicated by arrow (3). The dose rate at *b*, which is the required answer, is then obtained by finding the corresponding reading on the vertical scale. Following the horizontal line from *b* to *c*, this is seen to be 0.28 roentgens per hour.

Example (1b). At 30 minutes after an atomic explosion, the radiation dose rate due to fission products was found to be 260 roentgens per hour. How long will it be necessary to wait until the dose rate at this place falls to 1 roentgen per hour?

The arrow (1) in figure B.1*b* indicates "0.5 hour," i.e., 30 minutes, after the explosion, and arrow (2) shows the dose rate of "260 roentgens per hour." These lead to point *a*, representing the information given. As in the preceding example, a line through *a*, parallel to those on the chart, gives the variation of the radiation dose with time. Follow this line from *a* to *b*, where it meets the horizontal line for a dose rate of "1 roentgen per hour," indicated by arrow (3). The time represented by point *b* is then the time after the explosion at which the dose rate is 1 roentgen per hour. To find this time, follow the vertical line from *b* to *c*; the result, indicated by the point *c* is seen to be 52 hours after the explosion.

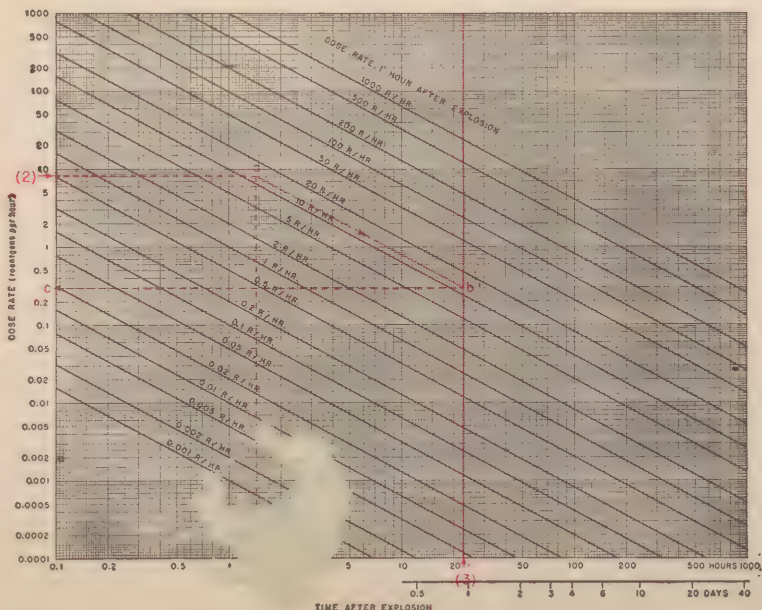


Figure B. 1a

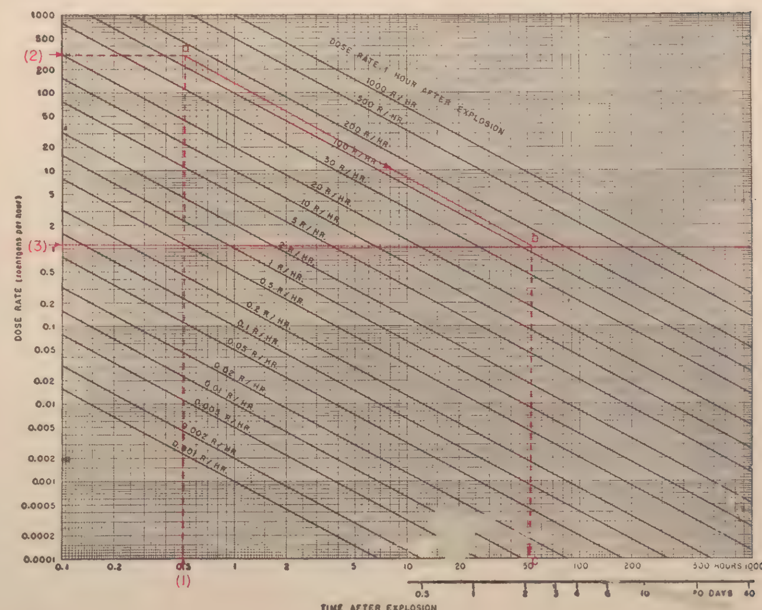


Figure B. 1b

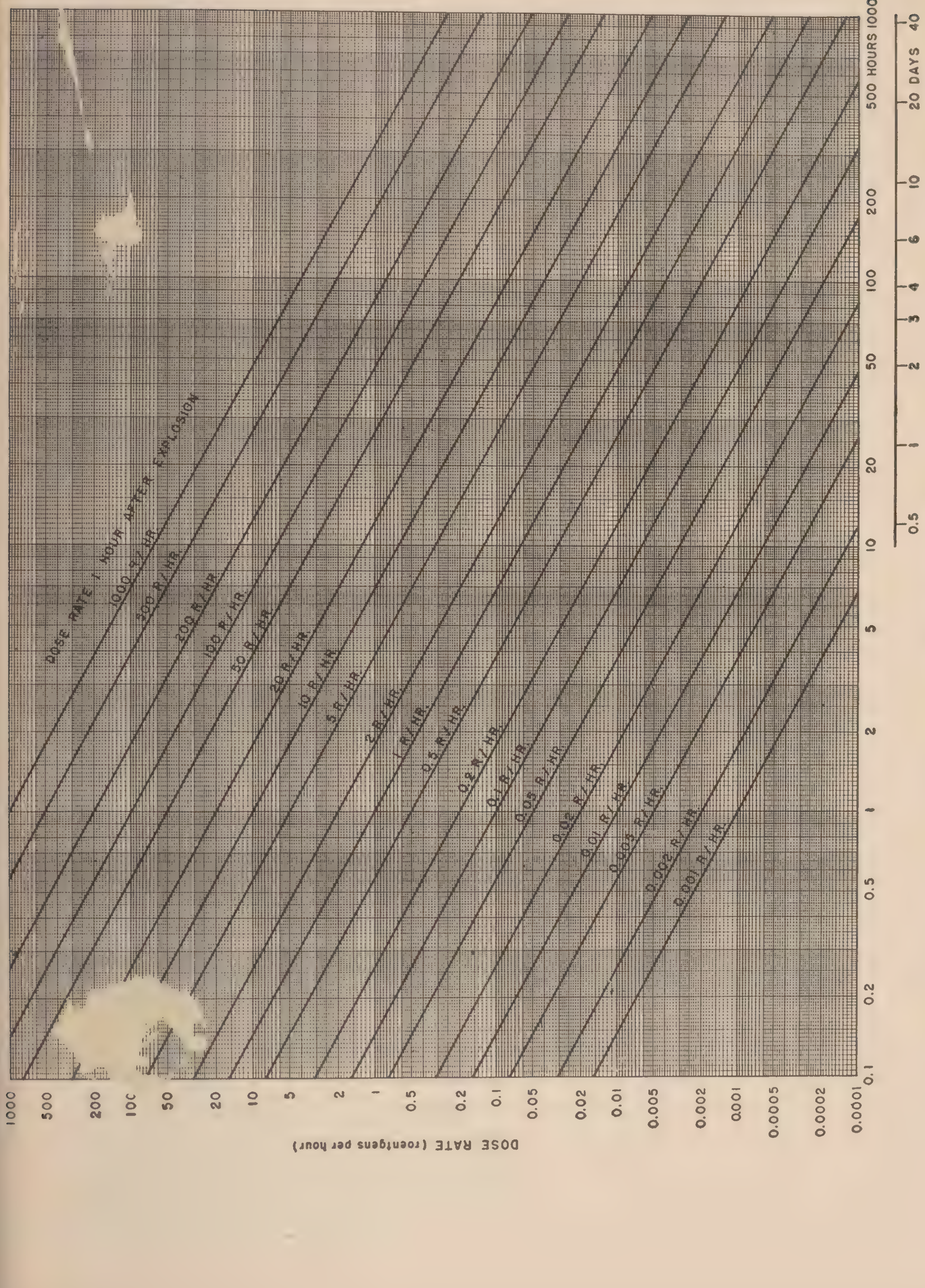


Figure B.1. Chart for estimation of dose rates at various times after an atomic explosion.

B.2. By integration of the decay equation in par. 2.26 it is possible to draw a graphical chart from which the allowable stay times in an area contaminated by *fission products* can be estimated. In figure B.2, for example, there is a series of curves for different times of stay (or exposure times). The ordinates (D/R_1) are the permissible total dose (D), in roentgens, divided by the dose rate (R_1), in roentgens per hour, at 1 hour after the explosion. The abscissas are the times after the explosion at which the exposure begins. The use of the figure is illustrated by the following examples:

Example (*2a*). The radiation intensity in a contaminated area is 70 roentgens per hour at 30 minutes after an atomic explosion. An operation to be performed in this area is estimated to require 4 hours, and the total radiation dosage which personnel will be allowed to accept is 25 roentgens. How long after the explosion will it be necessary to wait before starting the operation?

The first step is to determine R_1, the dose rate at 1 hour after the explosion, corresponding to 70 roentgens per hour at 30 minutes after. This is done by the method described in example (1*a*) above. In the present case, R_1 is found to be 30 roentgens per hour. Since D, the permissible total dose, is set at 25 roentgens, the value of D/R_1 is $25/30 = 0.83$. Now follow the horizontal line on figure B.2*a* for "$D/R_1 = 0.83$," as indicated by arrow (1) until it meets the curve for "4 hours exposure" at the point *a*. Since this curve is not one of those on the chart, it is interpolated, as shown; this can be done with sufficient accuracy. The time of starting the operation in the contaminated area is then given by the reading on the horizontal scale corresponding to the point *a*. By drawing the vertical line from *a* to *c*, the required time is seen to be 2 hours after the explosion.

Example (2*b*). The radiation intensity in a contaminated area is 70 roentgens per hour at 30 minutes after an atomic explosion. An operation is commenced at $2\frac{1}{2}$ hours after the explosion and personnel stay for 1 hour. What radiation dosage will they have received in this time?

It is necessary to know R_1, but this need not be determined as the first step. However, in this case, since the initial data are the same as in the preceding example, R_1 is known to be 30 roentgens per hour. To solve the problem, find the vertical line on figure B.2*b* marked by arrow (1), representing "$2\frac{1}{2}$ hours" after the explosion. Follow this up until it meets the curve for "1 hour" exposure time, indicated by the arrow (2) at the point *a*. The value of D/R_1 at this point is obtained from the vertical scale by following from *a* to *c*; the result is seen to be 0.27. Consequently, since D/R_1 is 0.27 and R_1 is 30, the dose received will be $30 \times 0.27 = 8.1$ roentgens.

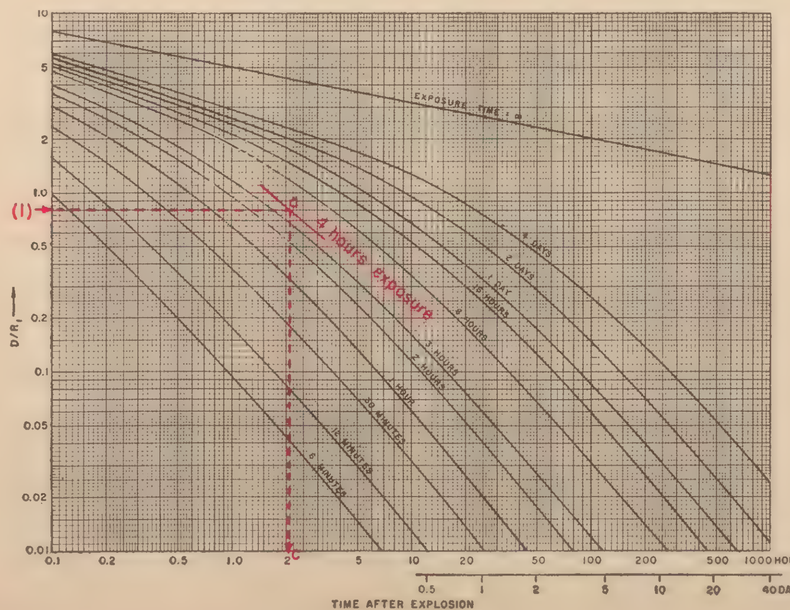


Figure B. 2a

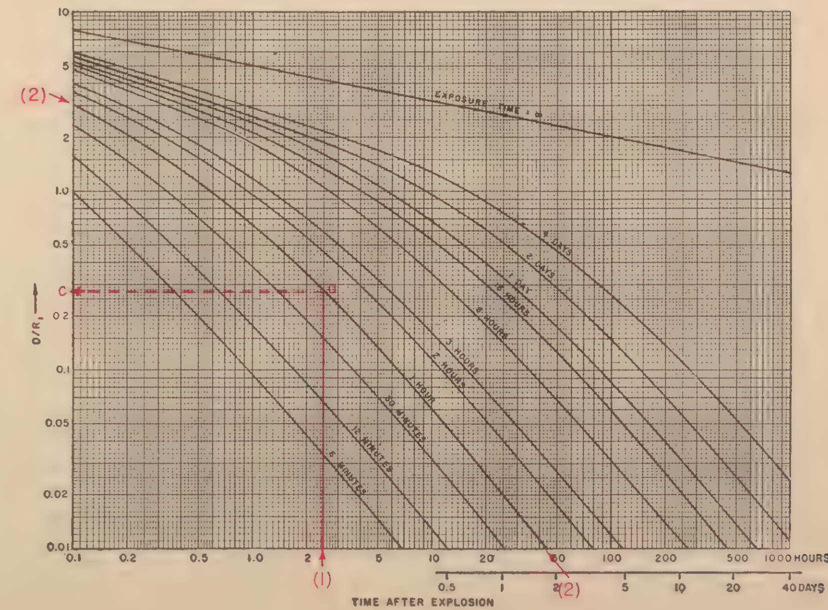


Figure B.2b

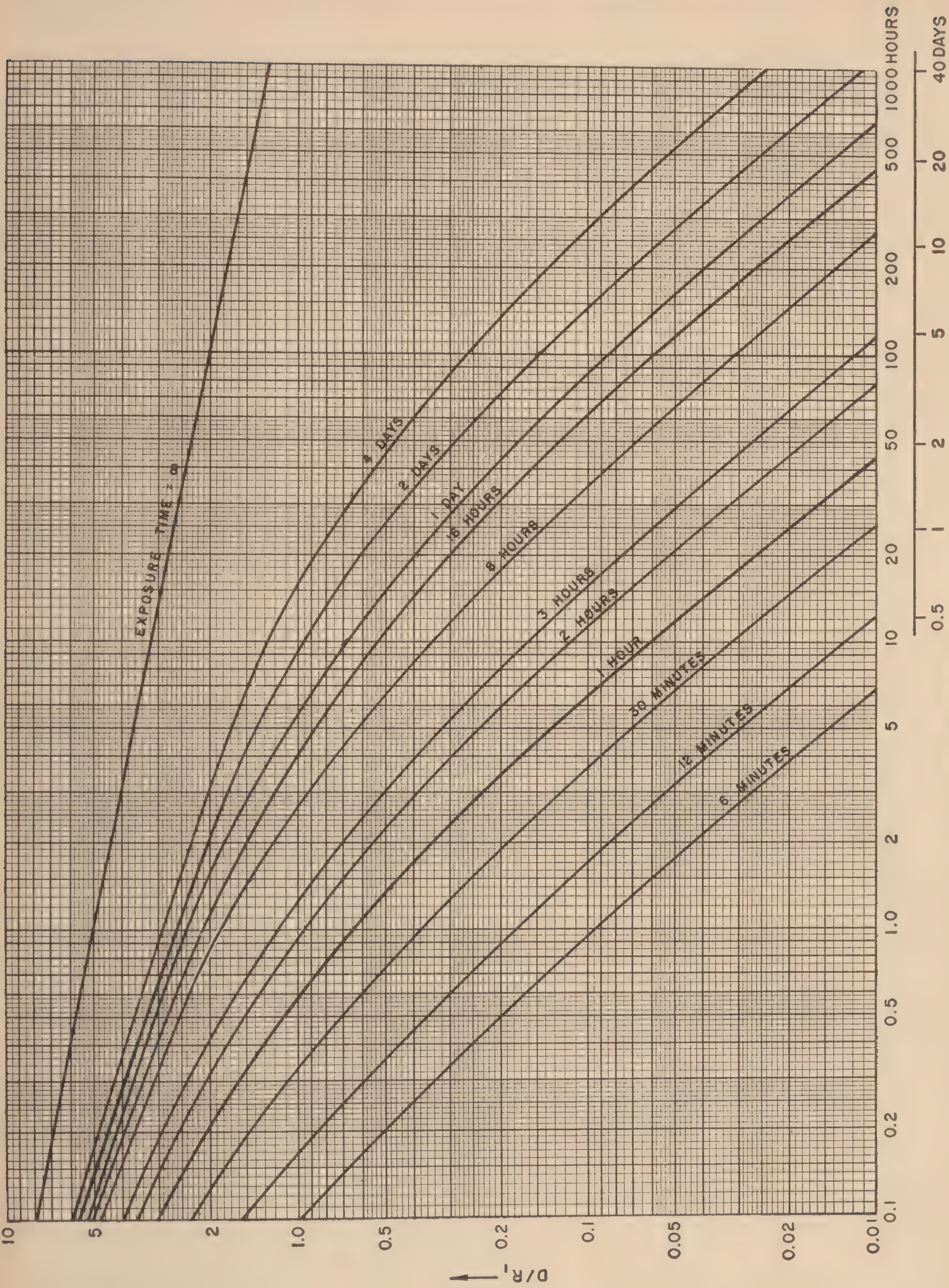


Figure B.2. *Chart for estimation of allowable stay times in contaminated areas (based on dose rate at one hour after burst).*

B.3. In the foregoing examples it was supposed that the dose rate in the contaminated area was measured at some time prior to starting an operation. If the dose rate is known *at* the time of starting, the calculations are somewhat simplified. In this case, figure B.3, also obtained by integration of the decay equation in par. 2.26, may be used. The ordinate is now D/R, which is the allowable dosage (D), in roentgens, divided by the radiation intensity (R), in roentgens per hour, observed *at the time of entry* into the contaminated area. The use of figure B.3 is quite similar to that of figure B.2, as shown by the examples given above, except that it is not necessary to determine R_1, the dose rate at 1 hour after the explosion. Two examples of the use of figure B.3 are given below. It may be noted that table 9.62 represents a limited number of points on figure B.3.

Example (3*a*). Upon entering a contaminated area at 4 hours after an atomic explosion, the dose rate R was observed to be 15 roentgens per hour. If the permissible dose (D) is 25 roentgens, what will be the allowable stay (or exposure) time?

The value of D/R is $25/15 = 1.66$. Find the horizontal line in figure B.3*a* for "$D/R = 1.66$," marked by arrow (1), and follow this until it meets the vertical line, indicated by arrow (2), for "4 hours" after the explosion, at the point *a*. This point is seen to fall just above the curve marked "2 hours" of exposure time. The allowable stay time will thus be slightly more than 2 hours.

Example (3*b*). Upon entering a contaminated area at 12 hours after an atomic explosion, the radiation intensity (R) was found to be 5 roentgens per hour. If an operation requiring $2\frac{1}{2}$ hours was then started, what would be the dose (D) received by personnel?

Follow the vertical line in figure B.3*b* for "12 hours" after the explosion, indicated by arrow (1), until it meets the curve for "$2\frac{1}{2}$ hours" exposure time. This curve is not one of those on the original figure, but its position may be estimated with sufficient accuracy by interpolation between "2 hours" and "3 hours," as shown by arrow (2). The value of D/R at the point *a*, where the vertical line and the exposure time curve meet, is obtained by following the horizontal line from *a* to *c*. Thus, D/R is found to be 2.3. Since R is given as 5 roentgens per hour, D is $2.3 \times 5 = 11.5$ roentgens, and this will be the dose received.

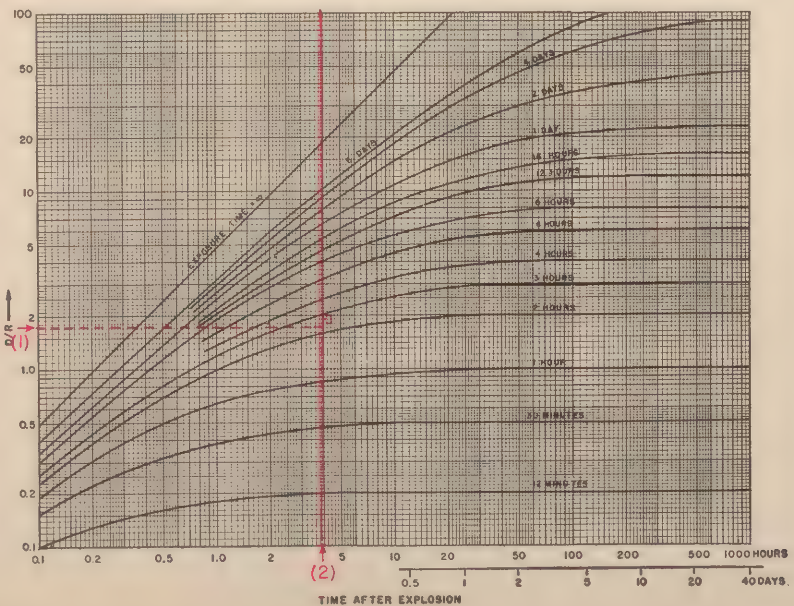


Figure B. 3a

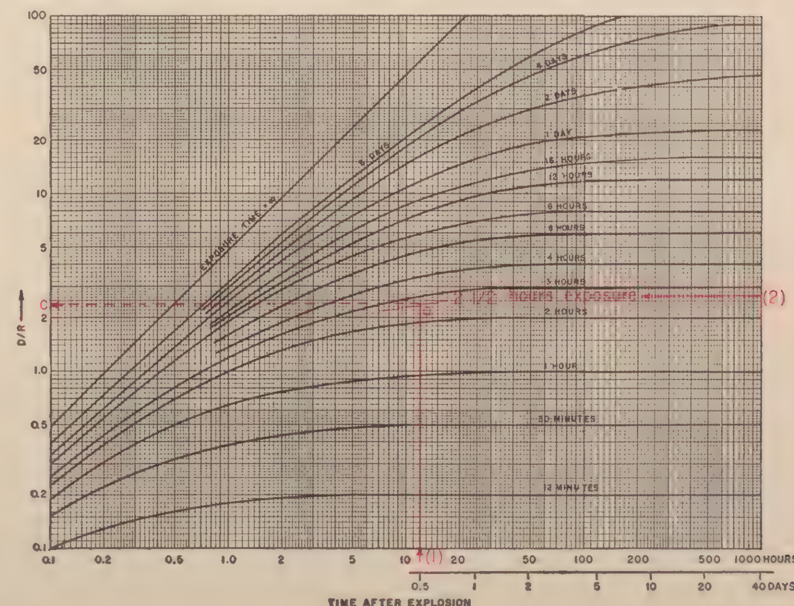


Figure B. 3b

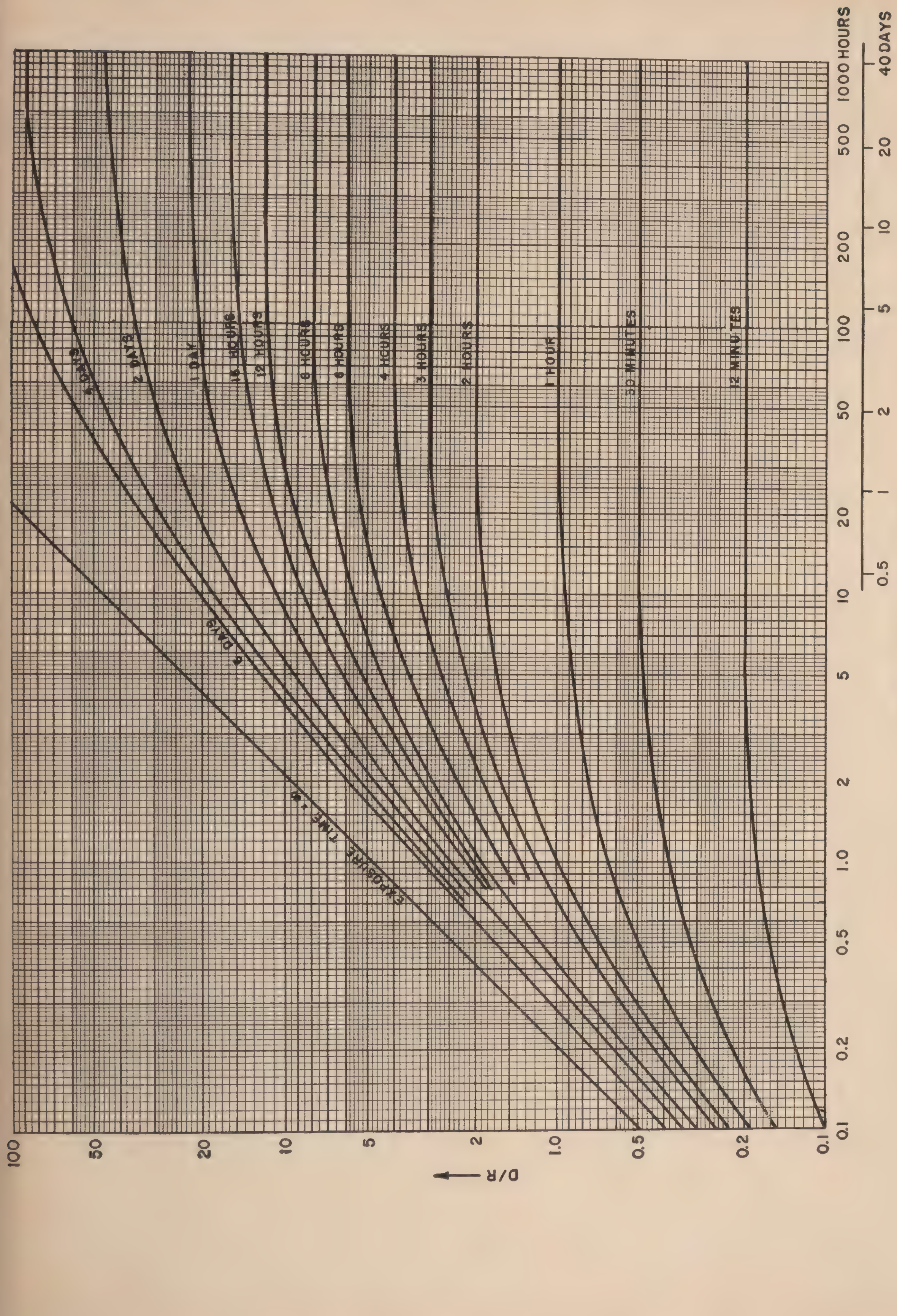


Figure B.3. Chart for estimation of allowable stay times in contaminated areas (based on dose rate at time of entry).

PUBLICATIONS AND MOTION PICTURE FILMS FOR GENERAL INDOCTRINATION OF MILITARY PERSONNEL IN EFFECTS OF ATOMIC WEAPONS

The following publications and motion picture films prepared for or by the Armed Services on various phases of the military aspects of atomic energy are listed in order to provide the interested reader with more detailed information on subjects beyond the scope of this volume, and to acquaint him with some of the items which he might find useful for training purposes. These publications and films have been given service-wide distribution and should be available in technical and film libraries, in headquarters files, or may be obtained through appropriate official channels.

Publications

Radiological Defense Manual (Armed Forces Special Weapons Project).

Volume I (1948). Official use only.

Prepared originally under the title of "Radiological Safety" by the Joint Crossroads Committee, this volume is primarily a text on the nuclear physics and radiation phenomena that pertain to an atomic explosion. A previous working knowledge of basic physics and algebra is desirable.

Volume III (1950). Unclassified.

A compilation of lectures on various aspects of atomic warfare with emphasis on the medical effects of the atomic bomb on personnel.

Volume IV (1950). Restricted.

An introduction to radiation detection instruments, containing descriptions of the various types of instruments and of the manner of their use.

The Effects of Atomic Weapons. Prepared for and in cooperation with the Department of Defense and the U. S. Atomic Energy Commission under the direction of the Los Alamos Scientific Laboratory (1950). Unclassified.

An authoritative handbook. The most comprehensive approach to atomic bomb phenomenology and effects which has been published to date within the security level of unclassified.

Atomic Energy and Radiological Defense. Armed Forces Special Weapons Project (1950). Restricted.

A nontechnical, easy-to-read presentation of the essentials of atomic energy and its relationship to radiological defense. The historical approach is a prominent feature. This is an AFSWP reprint of the Air Force Training Manual of the same name (AFTRC Manual No. 52–355–1, 1949). This publication has been further revised and reprinted as Air Force Manual 52–6 (June, 1951).

Atomic Energy Indoctrination. Department of the Army Pamphlet No. 20–110 (1950). Restricted.

A semitechnical discussion of military problems of radiological defense and nonmilitary applications of atomic energy, prepared especially for the use of instructors in the Army's atomic energy indoctrination program.

Nucleonics for the Navy. Department of the Navy, NAVPERS 10850 (1949). Official use only.

A well illustrated presentation, at an intermediate technical level, of the science involved in nuclear fission including a section on radiological instrumentation.

What You Should Know about the Atomic Bomb. Surgeon General, Department of the Army, Revised 1950.

A compendium of information on the medical effects of the atomic bomb. Somewhat more detailed than "Radiological Defense, Volume III" in certain respects, but covers much of the same ground.

Handbook of Atomic Weapons for Medical Officers. Department of Defense (1951).

A concise reference handbook of interest to Armed Forces medical officers. Includes operational and safety principles.

Motion Picture Films

Basic Physics of an Atomic Bomb. Running time 17 minutes; color; unclassified. AFSWP 5001, Army Misc. 7896, Navy MA 7404, Air Force TF1–4690.

An introduction to the atom and its size as related to known objects. The make-up of the nucleus and examples of natural and artificial radioactivity and an explanation of how nuclear fission makes the atomic bomb possible.

The Effects of Atomic Bomb Explosions. Running time 19 minutes; black and white; unclassified. AFSWP 5002, Army Misc 7815, Navy MA 7358, Air Force TF1–4688.

An explanation of the differing effects of the various types of detonations and the relative importance of blast effects and thermal and nuclear radiations for the various types of explosion. Contains a number of shots of actual explosions and bomb damage.

Self-Preservation in an Atomic Bomb Attack. Running time 18 minutes; black and white; unclassified. AFSWP 5003, Army AFSR 128, Navy MA 7325, Air Force TF1–4687.

The appropriate defensive actions that can be taken by individuals for self-protection in the event of different types of atomic bomb explosions are enacted by personnel in the uniforms of the various Armed Forces.

Medical Aspects of Nuclear Radiation. Running time 19 minutes; color; unclassified. AFSWP 5004, Army Misc 7897, Navy MA 7405, Air Force TF1–4691.

The story of the medical effects of nuclear radiation for the layman. Contains an explanation of the effects of radiation upon the human body. Covers the differing effects of internal and external radiation hazards, and compares them with the hazards of blast and heat from the standpoint of relative importance.

An Introduction to Radiation Detection Instruments. Running time 17 minutes; black and white; unclassified. AFSWP 5005, Army Misc 7773, Navy MA 7630A, Air Force TF1–4689.

Designed to show the reasons why radiation instruments are needed, as well as the methods of using them. Describes the different classes of instruments, how they are calibrated and read, and shows how they would be used in dealing with the results of an actual atomic attack.

General Effects of the Atomic Bomb on Hiroshima and Nagasaki. Running time 21 minutes; color; Restricted. Air Force TF1–4610.

A general study of the effects of the atomic bomb explosions at Hiroshima and Nagasaki on buildings, bridges, houses, and other structures.

The Damaging Effects of the Atomic Bomb Compared to Conventional Bombs. Running time 24 minutes; color; Restricted. Air Force TF1–4611.

Compares the physical destruction at Hiroshima and Nagasaki to the effects of conventional bombs on other cities.

The Effects of Strategic Air Attacks against Japan. Running time 48 minutes; color; Restricted. Air Force TF1–4613.

A general study of strategic bombing of Japan including the role of the atomic bomb in increasing the effectiveness of certain elements of strategic attack.

Medical Effects of the Atomic Bomb. Running time 32 minutes; 16-mm color; unclassified. Army PMF–5058.

Physics and physical destruction of the atomic bomb with relation to casualty effects; designed for the layman.

Medical Effects of the Atomic Bomb. Running time 28 minutes; 16-mm color; unclassified. Army PMF–5149.

Describes in layman's terms the responsibility of the medical profession in an atomic bomb attack and the importance of cooperation with community authorities. A continuation of the subject matter of PMF–5058; can well be used in conjunction with it.

Atomic Medical Effects at Hiroshima and Nagasaki. Running time 40 minutes; 16-mm black and white; Restricted. Army PMF–5148A.

A general review of the medical effects of the atomic explosions at Hiroshima and Nagasaki in medical language; intended for use of medical personnel.

Industrial Radiological Decontamination of Ships. 5 films, running time 10–18 minutes per film; black and white; unclassified. Navy MN 6949 a–e.

This series of five films covers a general study of the subject of radiological decontamination. The series begins with a review of physics necessary to understand the problem, then provides a study of decontamination practices and procedures, and covers the methods of health protection while working in contaminated areas.

INDEX

(References are to paragraph numbers)

*U.S. GOVERNMENT PRINTING OFFICE: 957000

NATIONAL LIBRARY OF MEDICINE

NLM 00097461 8